Dr. E. J. Butler,
with Kind regards
Lee M. Hutchins

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Identification and Control *of the* Phony Disease of the Peach

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NORMAL PHONY

By

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Identification and Control
of the
Phony Disease of the Peach

INTRODUCTION

A toll of more than 1,000,000 peach trees in Georgia, and a rapid march across the Southeast in little more than a decade, are significant signals of the potential danger of the phony disease.

Presenting no outward marks usually associated with a disease, most ingeniously concealing the secret of its contagious nature and hiding behind a clever mask of apparent health and vigor, the phony disease is well equipped to baffle and deceive not only the peach grower but also the professional plant pathologist. A mere curiosity 40 years ago in a Georgia orchard, this disease attracted little attention. It gained ground slowly during a period of many years, and not until 1915 was it recognized as becoming commercially important. The disease then began to work terrific destruction in the heavily planted, central Georgia district and to establish outposts far afield in previously non-phony territory. Heedless of changing geographic and climatic conditions in its path, and no respecter of State boundaries, the disease passed the frontiers of Florida, Alabama, Mississippi, Tennessee, and the Carolinas. The Mississippi and the Ohio Rivers were crossed to include parts of Louisiana, Texas, Arkansas, Oklahoma, Missouri and Illinois in the area of its present known distribution. No natural impediment has appeared to stay its progress.

Individual or scattered centers of relatively light infection occur in States new to the disease, but in these locations spread is progressing much as it did during the early history of the disease in Georgia. If allowed to go uncontrolled, there is grave danger that the phony disease may eventually destroy the peach industry in all sections where the infection has already been introduced. As yet no reason is known why the disease may not continue its onward march into peach-growing regions far beyond its present territorial limits.

It is important that growers, State agencies, and others, whose interests are allied with the industry of peach production, should be informed on the phony disease and should know how to recognize its characters, which are so unlike those of other plant diseases. In localities new to the disease as well as in territories where it has long thrived, vigilant extermination of infected trees must be maintained, if the industry is to endure. Of particular

moment is the discovery and eradication of new foci of infection before the disease becomes firmly entrenched.

Many years of research were required to penetrate the wall of mystery that surrounded the phony disease, but at last it yielded up its strange story. In the pages that follow, the discovery of the disease and its rise from obscurity to first-rank economic importance in less than half a century are recounted, fundamental facts that furnish a practical basis for control are discussed, aids to identification in field and laboratory are described and illustrated, and for those whose interests lead them more deeply into the subject is given a brief account of the experimental work that determined the cause and infectious nature of the disease.

DISTRIBUTION AND ECONOMIC IMPORTANCE

The first recorded observation of the disorder in peach trees now known as the phony disease was made at Marshallville, Georgia, a little more than 40 years ago. At that time a few orchard trees were found to be markedly stunted and bushy, although of rich foliage and healthy in appearance. Because of their small size in comparison with normal trees of the same age and variety, a tree dwarfed in this manner was called a "pony" tree. As the number of trees showing these symptoms did not rapidly increase at first, the matter was given little serious attention. Gradually, a tree here and there in commercial orchards near Marshallville showed the effects of some peculiar dwarfing influence, and by 1900 an occasional tree so affected was seen at Fort Valley, Georgia, 9 miles distant from Marshallville.

The phenomenon of the vigorous but dwarfed tree with its small crop of undersized peaches was not so conspicuous as to cause alarm until about 1915. In that year the late J. H. Hale, whose Fort Valley orchards then numbered about 100,000 trees, requested aid from the United States Department of Agriculture in a letter dated Fort Valley, Georgia, July 15, 1915, addressed to Dr. M. B. Waite, Pathologist in charge of Fruit Disease Investigations, Bureau of Plant Industry. In his letter, Mr. Hale's apprehension was expressed in the following terms:

> "As you know, Georgia has been quite seriously troubled in recent years with what some one has called 'Phoney Trees' in our peach orchards, trees with darker green foliage than any others in the orchards, very little new tip growth, a moderate set of fruit, which never grows to full size *** Going over the orchards of this district just now I discover that this disease is spreading rapidly. There are tens of thousands of trees so affected as to be of no commercial value in the future. *** it appears to be the most serious menace to the industry that we have ever had here, although I doubt if it is fully understood at the present time."

As a result of Mr. Hale's request, Dr. Waite spent several days in July, 1915, studying the characters and behavior of phony trees in the vicinity of Fort Valley and Marshallville. Here was indeed a very puzzling situation. Trees of apparently outstanding vigor were becoming dwarfed at the ages of 3 to 10 years

and older. They showed no lesions, cankers, galls, or hypertrophies. Root and branch, they were as clean as their normal neighbors. The leaves were deep green, flat, uniform in shape and outline, and showed no symptoms ordinarily associated with a disease. The fruits were well formed and of good color, but few in number and small. Scattered phony trees occurred in many orchards and their number appeared to be increasing. A few blocks of trees were already seriously affected.

Preliminary tests in 1915 indicated that the disease was not transmissible by budding and that neither the microscope nor the usual laboratory culture methods were efficacious in attempts to determine the cause. The disease and its progress became the subject of long-continued observation and research when in 1921 the United States Peach Disease Field Laboratory was established at Fort Valley, Georgia.

In 1915 losses due to the disease were only beginning to be felt, even in the older orchards. Profits were large in those years and it was natural that the growers should more or less ignore this bizarre newcomer which appeared at first actually to improve the vigor of the trees it attacked. Few indeed believed it to be a disease, and the situation was not regarded by many as a community problem. To foresee the great havoc that it was destined to work was of course impossible. From 1915 on, the disease increased at an alarming rate. Its mounting importance was obscured during 1919 and several succeeding years, by a severe outbreak of curculio and brown rot which caused great wastage of fruit in the orchards and sheds, in transit, and at the terminals. Also, the peach industry had developed to such an extent that there was a surplus of fruit and heavy grading out of the small phony peaches was not as significant as it would otherwise have been. Unfortunately, large quantities of phony fruit found its way to the markets, and its effect was reflected in lower prices for the better as well as for the lower grades.

Surveys made in 1921 and in several succeeding years showed that the inroads of the disease were coming on apace. The dark-green, bushy, phony trees appeared in ever-increasing numbers in orchards where it had become established. New orchards began to exhibit phony trees, and new counties were invaded. The area of distribution broadened constantly. Growers were soon to recognize the importance and subtle work of this most peculiar disease which does not kill, which for a time appears even to improve the vigor of the tree it attacks, but which permanently impairs the function of fruit production.

Progressive losses

Direct losses to the grower, on account of the phony disease, are due to a ruinous combination of reduced average size of ripe fruits and marked falling off in the actual number of fruits produced per tree. Although in shape, color, and shipping qualities phony peaches may compare favorably with normal peaches of the same variety, it is impossible to pack fancy or grade 1 packages with phony fruit, because of insufficient size of the phony

peaches, and the bulk of the fruit from phony trees has to be classified under the smaller commercial grades or graded out entirely. Hands who run the graders have frequently remarked that they can tell when baskets of peaches come in that were picked from phony trees, because such a large percentage of the fruits fall through the sizing machine into the culls. Comparative sizes of a normal Elberta peach, one from a tree in the first year of the phony disease and one from an old case of the disease, are shown in Figure 1.

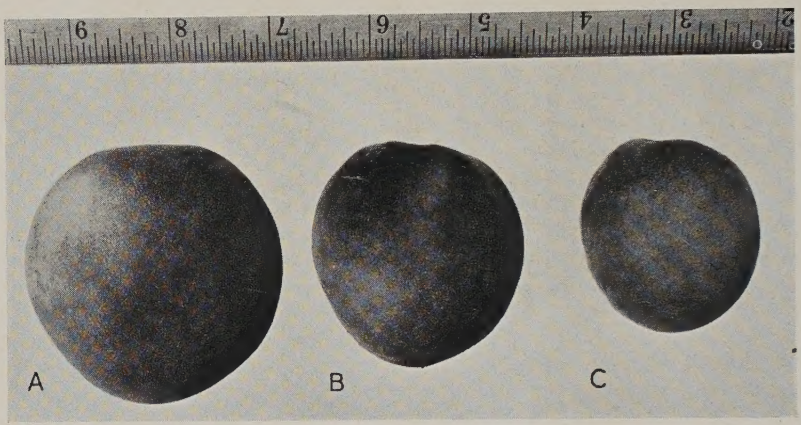

Figure 1.—Effect of phony disease on size of fruit: A, Normal peach; B, peach from a tree newly affected with phony disease; C, peach from a tree in which the phony disease was of longer standing. Elberta variety. (Photographed at Fort Valley, Ga., July, 1930)

When a new case of the phony disease develops in a bearing tree, and first definite symptoms of the disease appear before harvest, there may be no reduction in the actual number of fruits for that year, because the fruit-bearing twigs developed in an apparently normal manner the previous year; but the average size of the fruits will show a pronounced reduction this first year of the disease, and therefore the crop will neither pack in as fancy grades nor fill as many shipping containers as will a similar crop from a normal tree. A comparison between the commercial pack of the best fruits from a normal Hiley tree and the best fruits from a new case of the phony disease in that variety is shown in Figure 2.

With increasing age of the disease in a tree, dwarfing effects become more and more pronounced, and annual bearing wood is correspondingly reduced. Up to a certain point, annual crop production of a phony tree is therefore progressively smaller than that of a normal tree of the same age, variety, and location. An unusual opportunity to collect data illustrating this feature

Figure 2.—Effect of phony disease on commercial pack, showing at left best grade (diameter 1⅞ to 2¼ inches) of fruit from normal tree, and at right best grade (diameter 1½ to 1⅞ inches) from phony tree. Hiley variety. Fruit packed in Georgia 6-cup crate. (Photographed at Fort Valley, Ga., July, 1928)

was presented in a certain Fort Valley orchard of the Hiley variety. In the course of this investigation accurate charts of the orchard were made for each of 12 successive years, and the year that each phony tree first evidenced symptoms of the disease was recorded. This orchard of 2,100 trees was planted in the late winter of 1918-19. During the third growing season (1921) 90 trees became typically phony. The number of phony trees increased by yearly increments until, by the end of 1927, more than 1,200 trees of the original planting had contracted the disease. In 1928, crop records were made on trees of the original planting, which records included crops from trees still normal, and from those that first showed symptoms of the disease, respectively by years, in 1921 through 1928. After the entire crop for each tree was sized, it was placed in cups of the usual Georgia carrier or crate, and arranged in such manner that a photograph could be made. Figure 3 shows, respectively, the crop from a normal tree, from a new case of the disease, and from trees that had been known to exhibit phony characters continuously from 1 year to, and including, 8 years.

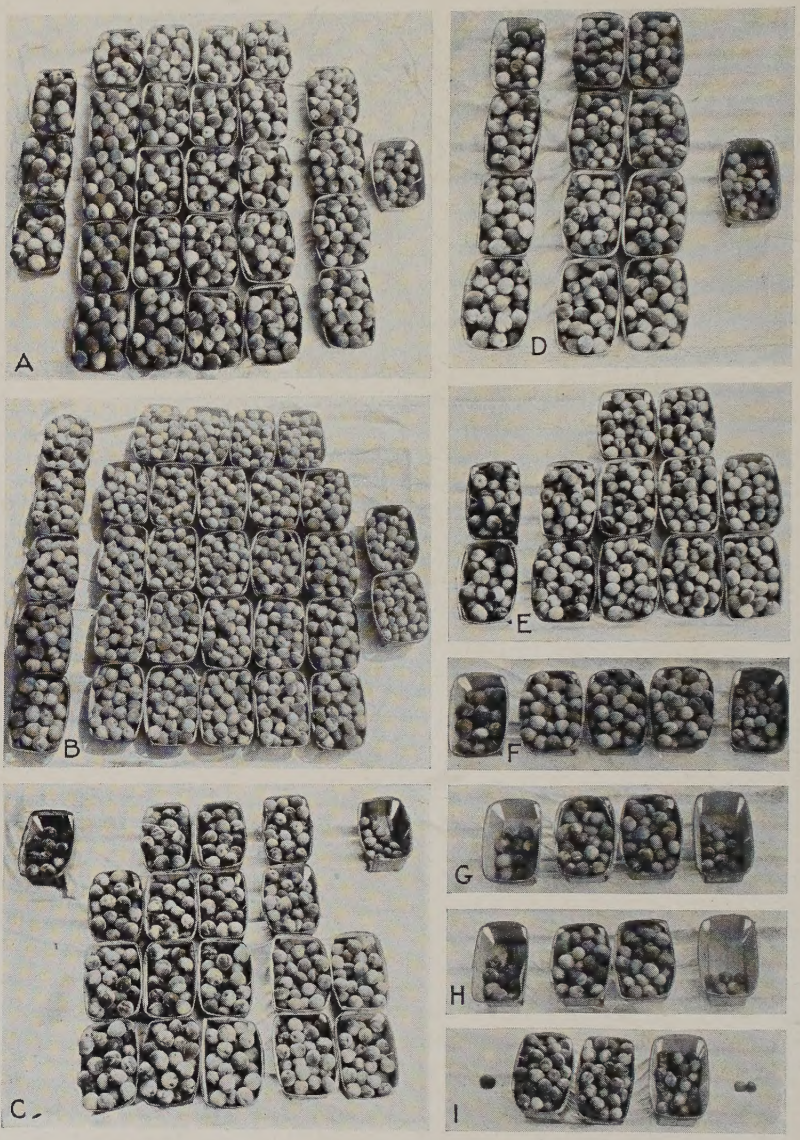

Figure 3.—Yields of peaches in 1928 from an orchard of the Hiley variety at Fort Valley, Ga., planted in 1919, from trees representing respectively the normal condition and the effects of the duration of the phony disease from 1 to 8 years, showing reduction of the crop with increasing age of the disease. Duration is counted from the time when phony characters first became apparent in the tree and does not include the incubation period. A, Fruit from normal tree (Grade 1, 3 cups; Grade 2, 20 cups; Grade 3, 4 cups; Grade 4, ½ cup); B, fruit from tree that first showed phony characters in the spring of 1928 (Grade 2, 5 cups; Grade 3, 24 cups; Grade 4, 2 cups); C, fruit from tree diseased 2 years; D, 3 years; E, 4 years; F, 5 years; G, 6 years; H, 7 years; I, 8 years.

Deceived by conspicuous bloom, luxuriant foliage, and an apparently satisfactory set of fruit that is well formed and develops high color, growers unfamiliar with the phony disease are often incognizant of the real losses involved. Especially is this true when the percentage of phony trees in an orchard is not large, and when the trees have attained good size before exhibiting symptoms of the disease. The crop is generally harvested by several pickings, on different dates, and although phony fruit tends to ripen slightly earlier than normal fruit, there is considerable overlapping, and the two sorts are readily mixed in the picking baskets. For a phony tree as compared with a normal tree, the average size and the actual number of fruits is in this manner easily lost sight of, and the unproductiveness of the phony tree is frequently not appreciated until an important percentage of trees in an orchard have contracted the disease. Actual crop records by individual trees, as illustrated in Figure 3, furnish impressive and incontrovertible evidence to condemn the phony tree from the standpoint of commercial fruit production.

Against each orchard tree, as an intended unit of production, must be charged a proportion of the cost of capital invested for land, buildings, purchase and planting of nursery trees, and implements and machinery, as must also be charged annual costs of operation and maintenance, such as cultivation, fertilizers, pruning, spraying, harvesting, repairs to buildings and equipment, improvements, insurance, taxes, supervision, and labor. Therefore, in every orchard operated for profit, of first concern to the grower must be long life and efficiency of the individual tree as a unit of production. Impairment of these functions will assume importance depending upon severity and number of trees affected.

Comparison with other virus diseases.

After the grower has selected the proper soil and climate for the peach and has followed good cultural practices, his trees may still be subject to numerous parasitic and nonparasitic diseases and injuries, among the most important of which are those that permanently diminish the capacity for fruit production or threaten the life of the tree. In this latter category, and potentially the most dangerous of all, are the infectious virus diseases, of which peach yellows, peach rosette and little peach are old and famous examples.

It is apparent that classification should be one of the first points to study in researches on a new plant disease. Remedial or control measures must depend upon whether the disease be physiological, nutritional, genetic, infectious, or a combination of two or more of these conditions. As will appear in subsequent pages, a long series of observations and experiments finally unmasked the phony disease and revealed that it is definitely infectious. It is now considered to be a new member of the peach yellows group of virus diseases.

For the purposes of this discussion, a virus may be thought of as an exceedingly minute infective principle, too small to be

seen through the microscope. Virus diseases are in many cases extremely infectious, and numbered among them are some of the most dreaded contagions in cultivated plants, domestic animals, and man. From the progress of recent researches, mosaic or streak diseases caused by viruses have now become familiar to growers of sugarcane, tobacco, vegetables, small fruits, and ornamental plants. Hog cholera, foot-and-mouth disease, and rabies are well-known virus diseases of animals. Smallpox, chickenpox, mumps, and measles are common virus diseases of man.

Although of totally different characters from any other known member of the group, the newly added phony disease presents many problems in common with peach yellows, little peach, and peach rosette; notably problems of distribution, economic importance and control.

Peach yellows is accompanied by rolling and yellowing of the leaves; premature ripening of fruit that is often misshapen, generally splotched with red, and bears red streaks in the flesh; spindling sprouts and sucker growth from the framework limbs; marked weakening and finally death of the trees within a few years. Yellows is highly infectious and is mostly confined to the northeastern quarter of the United States, where it has been known for more than a century and has outranked all other diseases in actual destruction of peach trees.

Peach rosette, a disease primarily of the southeastern quarter of the United States, is characterized by extremely short internodes that closely appress the newly formed leaves into rosettes; by yellowing and rolling of the foliage; and by red spotting and early fall of the larger leaves. A tree attacked by peach rosette usually matures no fruit after the symptoms of the disease appear, and in most cases death of the tree occurs the same year that the disease becomes identifiable. Self-elimination through early death of the tree is an important factor in the natural control of peach rosette, and this disease is less important than yellows.

Little peach is very infectious and spreads rapidly through an orchard or a locality. It is characterized by yellowing of the foliage and by abnormally small peaches that ripen late. After having the disease about four years, a little-peach tree invariably dies. This disease has caused serious losses, mostly in Michigan and in other northern States.

Of these three diseases, peach yellows is most widely distributed and has been economically the most important. In the heart of the heavily planted central Georgia peach belt, the phony disease has already approached the seriousness of peach yellows at its worst. First observed near Marshallville, Georgia, something over 40 years ago, the phony disease smoldered in comparative obscurity for many years, but during this period migrated in all directions to points several miles distant from the place of dis-

J. M. Shull, Artist.

Plate I.—Hiley Peaches. Left, normal; right, phony. Natural size.

covery. By 1915, a formidable reservoir of inoculum, comprising thousands of phony trees, had been built up in this area.

Destructiveness and spread.

In his prognostic of the phony disease in 1915, J. H. Hale stated in part: "It appears to be the most serious menace to the industry that we have ever had here, although I doubt if it is fully understood at the present time." Subsequent losses have fully substantiated the prophecy implied. In their prime, Mr. Hale's immense Georgia orchards, located about 9 miles from Marshallville, covered 1,000 acres. At the height of the season 15 refrigerator cars of peaches were shipped daily, and the total for a year ran as high as 250 carloads. The phony disease first appeared in an occasional tree in these orchards about the year 1900. It progressed slowly, was little noticed at first, and did not reach menacing proportions until about 1915. From that time on it spread at an alarming rate, as rapid consolidation in the infested area took place. Like a huge conflagration, the disease got entirely out of bounds and during the succeeding years swept a great path of destruction. By 1927, more than 99 per cent of the trees in the most seriously affected blocks of the Hale orchards were phony. In 1928, not a carload of peaches was shipped from these orchards, largely on account of the phony disease; the situation had become hopeless, and all blocks of bearing trees were cut down. Some 600 acres of grain was then planted where had recently stood peach orchards that were numbered among Georgia's finest and most productive.

Several other large plantings in the same general vicinity suffered in like proportion. A block of 2,100 trees of the Hiley variety, planted in January, 1919, was observed to have 90 trees affected with the phony disease in the summer of 1921. The number of phony trees increased by yearly increments until, in 1927, over 1,200 trees of the original planting were definitely phony. By 1931, more than 99 per cent of the trees had contracted the disease.

A planting, isolated from the above-mentioned district by several miles of farm lands and woodlands, was inspected by the writer in 1921. Of about 50,000 peach trees of various ages, less than 0.1 per cent were found to be phony. By 1925, although scattered and in unimportant numbers, phony trees were much more prevalent in these orchards. During 1931 and 1932, the inspectors of the Phony Peach Eradication Campaign found and cut down 3,980 phony trees here. In the absence of eradication measures in these orchards, the number of trees showing the disease had increased from less than 50 to a total of 3,980 in 12 years, most of the increase having occurred during the last 4 or 5 years of the period.

It has been stated that the phony tree may, for a period of several years, simulate a healthy, productive condition, and that only by means of actual crop records from individual trees can a grower become aware of the extent of this deceptive feature of the disease. By detailed and extensive mapping of orchards

over a period of many years it has been shown that the phony disease does not spread in the close-colony formation known to accompany local spread of peach yellows. New cases of the phony disease are, in general, rather evenly dispersed over a planting, with no sharply discernible locational relation to previously existing cases in the same orchard.

In the last mentioned orchard the grower carried the usual overhead charges and operation costs, which were apportioned to each tree as a unit of production. But here 3,980 of the units were nonproductive phony trees. Actually these diseased trees were dispersed over the entire planting, but if conceived of as assembled in orchard formation they would have covered an area of 37 acres. Not only was this grower carrying overhead charges and expensive maintenance for the equivalent of 37 acres of profitless phony trees, but also, of vastly greater importance to himself and the community, he was unknowingly nursing the propagation and accumulation of a huge volume of the infective virus. By spreading from thousands of scattered phony trees, the disease would soon reduce the grower's margin of profit until he would be operating at a loss; it would eventually work the destruction of his own orchards, and invade all adjacent plantings, there to repeat the ruinous cycle.

Mention should be made here of the exceedingly destructive results of the phony disease in young orchards planted in a community heavily infested with the disease. Commercial peach growers customarily plant new orchards from time to time, in order to provide replacements for old orchards, or for expansion of business. The highest incidence of the disease on the author's records, for a commercial orchard of young trees, occurred in one in which 60 per cent of the trees were phony when 4 years old. On two sides of this orchard, were old orchards in which phony trees were very numerous. The fact that there was such a large percentage of phony trees in this young orchard, coupled with the certainty that the disease would sweep the entire planting, would preclude any profitable returns and make replanting hazardous. The trees were cut down, and the land was devoted to farm crops. The grower had borne the original costs and the cost of four years of expensive maintenance, without receiving any appreciable returns.

It may be taken as an ominous sign when from 3 to 5 per cent of the trees in a young orchard are phony at the end of the third growing season after planting. This represents a distribution of the infection and a rapidity of spread sufficient to bring about the commercial ruin of the orchard within a few years. In the absence of control measures, well over 50 per cent of the trees in such an orchard may be expected to be phony by the time they are 8 years old, and more than 99 per cent may be diseased at 12 years old. This describes a condition that has frequently occurred in the region of heavy infestation.

Not only has the phony disease, in parts of central Georgia, been accountable for losses comparable to those occasioned by peach yellows in other sections of the country, but also, in the

J. M. Shull, Artist.

Plate II.—Normal Early Rose peach foliage; two-thirds natural size.

J. M. Shull, Artist.

Plate III.—Phony Early Rose peach foliage; two-thirds natural size.

rapidity of its dissemination over a great territory, this disease is again the equal of yellows as a menace to the peach industry. The history of the phony disease from its first recorded observation to the present time covers a period of less than 50 years. Its rise to first rank economic importance in Georgia and its migration to 12 additional States has occurred within little more than a decade.

The known distribution of the phony disease, in 1928, is shown in Figure 4, and is based on such surveys as the research laboratory at Fort Valley had been able to make intermittently over a period of a few years. In general, passing outward from Fort Valley, the disease was found to become less and less prevalent, until finally it disappeared, approximately at the boundary lines shown. Numerous inspection trips to orchards located from 50 to 100 miles beyond the then-known boundaries did not reveal the presence of the disease, neither was it found on occasional visits to nearby or to distant States. It remained for the Phony Peach Eradication Campaign, organized in 1929, to conduct more extensive, tree-to-tree surveys both in commercial and in home orchards. The known distribution of the phony disease as of January 1, 1933, based on the findings of that organization, is shown in Figure 5.

During the four years from 1929, to 1932, the Phony Peach Eradication Campaign accomplished the inspection of 40,538,560 peach trees, practically all of which were in commercial orchards, and of this number, 449,754 trees were found to be phony. By far the largest percentage of phony trees ocurred in Georgia, where 437,038 cases of the disease were found and destroyed. In States other than Georgia, during this same period of years, 12,716 phony trees were located and destroyed. Home orchards were inspected in 57 Georgia counties and yielded 11,527 phony trees. Most heavily infested of all was the Georgia county adjoining the locality in which the disease was first discovered, and from which locality was initiated the building-up of a large local colony and the general spread of the disease over the Southeast.

The foregoing do not include losses from the phony disease prior to 1929. J. H. Hale wrote in 1915: "Going over the orchards of this district just now I discover that this disease is spreading rapidly. There are tens of thousands of trees so affected as to be of no commercial value in the future." The manner in which the disease later swept over the central Georgia district has been mentioned in the preceding discussion. The writer visited this section in 1917 and has been closely in touch with the situation since the spring of 1921. His estimate that up to the present time the phony disease has taken a toll of more than 1,000,000 peach trees in commercial orchards of Georgia is believed to be conservative and in no way to exaggerate the gravity of the problem. Beginning with 1921, the local spread of the disease has been recorded from year to year on orchard maps representing never less than 10,000 trees and reaching a maximum of 35,000. During these years annual surveys progressing outwards from the original colony of phony trees have plainly

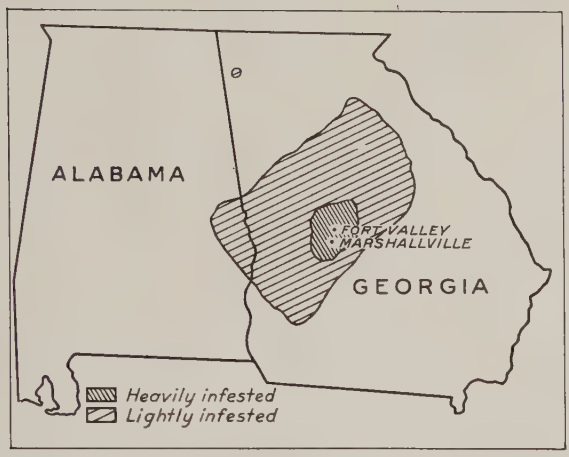

Figure 4.—Known distribution of the phony disease of the peach, December, 1928. (First known occurrence was near Marshallville, Ga.)

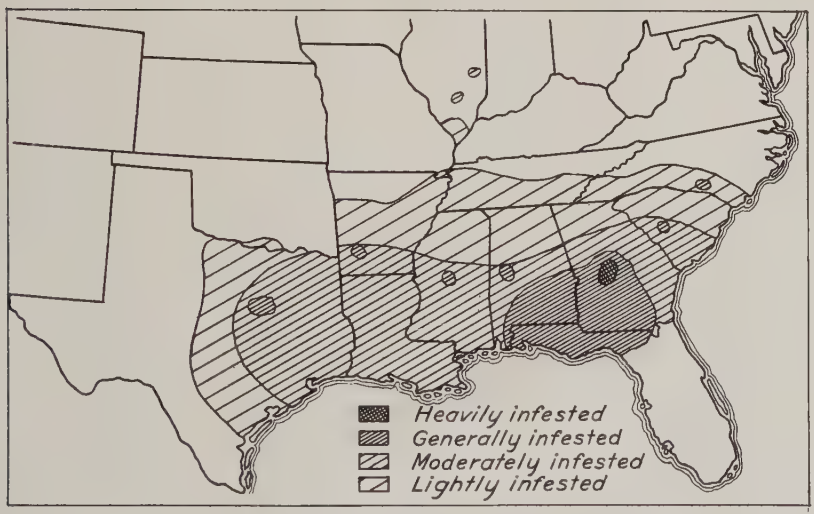

Figure 5.—Known distribution of the phony disease of the peach, January 1, 1933.

indicated the gradual enlargement of that colony, the appearance of new outposts of infection, and the local spread of the disease from these new centers.

The age of the disease in the phony tree frequently may be determined with considerable accuracy, as will be shown later. The work of the Phony Peach Eradication Campaign has clearly indicated that recent and extensive new distribution of the disease has been accidentally accomplished by some means other than natural spread from the original colony in Georgia.

Once introduced into a commercial peach district new to the disease, the infection has, in all of the States where it has been found, proved its ability to spread and begin the formation of a local colony, much as it did in the early years of its history in Georgia. If a typical Georgia colony may be taken as a criterion and if control measures are not enforced, a period of something less than 15 years may elapse in the new centers of very sparse infection before the disease becomes so prevalent as to ruin certain commercial blocks of trees. After that time losses may be expected to mount rapidly, and within a few years they will reach such proportions that it will no longer be possible to maintain a profitable commercial peach industry.

The fact that the phony tree often simulates a healthy appearance, that the infection may be working in the tree from a year and a half to two years before the characters of the disease become very marked, or even apparent, and that infected trees do not die of the disease, frequently makes the disease more difficult of identification than peach yellows and harder to eradicate. Particularly is this true in home orchards of mixed varieties and in wild seedlings.

It may be said in general that the phony disease does not spread as rapidly as peach yellows, and this is especially true where relatively few trees in a community are infected. When, however, the phony disease has become as prevalent as it now is in portions of the central Georgia area, its natural dissemination, if inadequately controlled, becomes so rapid that it is impossible to maintain orchards in a profitable bearing condition.

There is no indication that the ultimate natural frontiers of the phony disease have been reached, and if the disease is allowed to continue in its progress, uninterrupted by artificial control measures, its territory of distribution may eventually expand to include peach-producing regions far beyond the present known area as shown in Figure 5.

To classify the phony disease with the peach yellows group of virus diseases is indeed to associate it with some of the most dangerous enemies of the peach. Unless its progress shall be arrested, there is a grave prospect that the phony disease may become the most important member of the group. It has been shown (1) that in the heart of the central Georgia district the disease has already caused losses comparable to those occasioned by yellows in other territories of similar proportions; (2) that in a brief history of 40 odd years the phony disease has invaded 13 States, covering as much territory as that over which peach

yellows has spread in more than a century; (3) that the ultimate geographical frontiers of the phony disease have in all probability not been reached; and (4) that in the field this disease is on the whole more difficult of identification than yellows and when once entrenched is harder to eradicate. Indeed, at the present time the phony disease appears to be a more menacing disease than yellows.

Bitter experience proves that to trifle with the phony disease in commercial peach districts is to court disaster. Those familiar with the disease would be neglecting an important duty in failing to impress the extreme necessity of exerting every effort to bring this disease under control.

CONTROL

It is the purpose of the present chapter to outline some of the fundamental facts that furnish a basis for practical control of the phony disease rather than to describe the organization and work of agencies delegated to the task.*

In the light of certain characteristics common to the virus diseases of the peach-yellows group, including the newly added phony disease, and in view of present knowledge concerning these diseases, it becomes apparent that efficient eradication is essential for control.

The ultramicroscopic viruses that respectively cause these diseases carry on their activities in the internal tissues of the plant and can not be reached by the application of surface sprays. Infection is usually deep-seated in the tree before any external symptoms are apparent, and the entire tree is doomed as early as one or another of the diseases can be identified. No seedling or named variety of the peach has been known to resist the attack of any of these viruses. Treatments of the soil about the roots of the diseased trees, by the application of any of various chemicals and fertilizers, have been ineffectual as a cure, as have also direct injections of any materials into the trees. All soil and other environmental conditions that will support the life of a peach tree are apparently suitable for the development of these viruses in the plant.

For peach yellows, little peach, and rosette, it has been proved by long experience that effective control may be accomplished over a period of years, by thorough and repeated inspections of orchards and adjacent premises, accompanied by the immediate destruction of all trees in which one or another of the diseases can be identified. Famous in this connection is the Michigan statute enacted in 1875 which provided for obligatory orchard inspections and the compulsory destruction of all trees in which peach yellows could be identified.

* Field headquarters of Federal and State cooperative phony peach activities are maintained at the U. S. Peach Disease Laboratory, Fort Valley, Georgia. The Bureau of Plant Industry of the United States Department of Agriculture and the Office of the State Entomologist began active cooperation in eradication of the phony peach disease July 1, 1929. Informal cooperative development of the eradication campaign has been extended more recently to other States involved.

Also, it has been repeatedly demonstrated for yellows, rosette, and little peach, that if eradication be promptly undertaken before infection has become widespread in an orchard, a locality, or a large district, control is most effective and least expensive to maintain. After these diseases are firmly established in a community and a large number of trees are affected, the actual work of inspection is greatly multiplied and a proportionately longer time will be required to reduce the percentage of diseased trees to commercially unimportant numbers. The same rule may be expected to apply to the phony disease.

All of these diseases of the peach yellows group, including the phony disease, pass through an incubation stage in the tree; that is, a period of time elapses between the introduction of the virus and the development of specific abnormal characters that are sufficiently pronounced to render possible the identification of one or another of these diseases. The vector or intermediate agency that transmits the virus of the phony disease from tree to tree in nature has never been discovered. The period of the year during which natural spread takes place is therefore not certain and must be assumed from general observations on behavior. When these diseases are artificially inoculated into orchard trees by budding or scion grafting (yellows, rosette, and little peach) or by root grafting (phony disease), the incubation period is ordinarily several months, sometimes a year or more, for the first three members of the group, and about 18 months for the phony disease. It may be assumed that the incubation period following natural inoculation may be somewhat comparable. During this period the infective virus is being multiplied and distributed in the plant. Even though no external characters of disease may be evident to the observer, such trees are actually infected and should be regarded as hidden reservoirs of the infective virus.

It is apparent that trees in which the characters of a virus disease can be defined, as well as trees in which such a disease is in the incubation stage, are sources of inoculum for spreading the infection. Destruction of all visibly affected trees in an orchard or a community, therefore, does not mean that the disease has been entirely eradicated with the first inspection nor that its spread has been completely arrested. Only those cases have been removed that were plainly identifiable, and with them a corresponding amount of inoculum. As more cases emerge from the incubation stage and are destroyed, the reservoir of the infective virus is further diminished, and spread to healthy trees will be less, until finally, after repeated combing of the orchards for diseased trees, the source of inoculum becomes exhausted and the disease disappears from the orchard.

Either peach yellows or little peach, in a violent outbreak and in the absence of eradication measures, may spread rapidly and devastate the industry of peach production over a large area. However, in such a territory nearly all cultivated and wild peach trees will have succumbed within a few years, and self-elimination of the disease will have been largely accomplished through

destruction of the principal host plant. The industry may then be rebuilt by new plantings, if attention is given to occasional sporadic outbreaks as they appear.

Inherent characters preclude any such claims for the phony disease, and here again it should be emphatically recalled that phony trees neither die of the disease nor do they ever recover from it. Living trees are on record that have exhibited phony characters for the past 12 years. Regardless of the duration of the phony disease in the tree, infected tissues (roots) never fail to transmit the disease to normal peach trees, by a method of artificial inoculation hereinafter described.

The longevity of the phony tree, with its ever-present infective virus and its simulation of a healthy condition, constitutes a serious problem. Phony trees in dooryards and in places that escape cultivation, year after year may introduce the disease anew into nearby commercial orchards even though the orchardist himself may practice thorough eradication. In regions where home orchards and wild peach trees abound, not only does the presence of the phony disease menace the local grower, but a still greater hazard exists in that by following irregular chains of noncommercial plantings the disease may travel, unobserved, to distant parts, thus bridging the gaps between widely separated centers of commercial peach production. At the present time no sure means other than eradication is known as a control measure. Unless it be vanquished in these wild strongholds, the phony disease may ever be recurrent in regions into which it has once been introduced, and the area of its distribution may be vastly enlarged.

Abandoned orchards, home orchards, and seedling peach trees in dooryards, in woods, and in out-of-the-way places must be included in any well-organized campaign to eradicate the phony disease. Seeds from canning factories as well as "drops" from orchard trees and culls from the packing sheds should be disposed of in such a way as not to produce quantities of wild seedlings, which are worthless, difficult of access, and hard to inspect. Such trees are favorite breeding grounds for virus diseases and for many other enemies of the peach. In the districts where the phony disease occurs, wholesale destruction of all valueless peach trees is strongly advised and is more efficient and more economical than repeated inspection of such places and cutting out diseased trees only as they are found.

It should be remembered that the causal germ of the phony disease resides in the roots of the infected trees, and that the disease cannot be spread by means of phony fruit, seeds, buds, or scions. Insofar as this disease is concerned, shipments of fruit containing phony peaches in no way endanger the peach industries of communities through which such consignments may pass or in which they may be consumed. No discrimination against peaches from the phony disease area is justifiable, therefore, on the basis that they might possibly introduce or disseminate the disease.

Previous to the advent of the phony disease, no contagious

constitutional tree disorder of equal moment had been visited upon the peach culture of the Southeast. Peach yellows has occasionally touched the northern fringe of this territory, and peach rosette has been endemic there, but never has the latter disease been difficult to control. Growers of this region have therefore inherited no precedent from earlier experience with the same or a similar malady to warn them of the potential danger from the spread of the phony disease and to guide them in the necessary control measures. Although a vivid reality in central Georgia, until recently this disease was not recognized throughout the greater portion of its present extensive territory. Few growers beyond the borders of Georgia had been given an opportunity even to hear of the phony disease and its work in that State. An orchardist uninformed on the disease could not be expected to give more than casual attention to the presence of a few healthy-appearing phony trees in his plantings. Least of all would he be inclined to attribute the phenomenon to a contagious disease. Cursory examination of detached specimens of twig, leaf, or fruit could scarcely arouse the suspicions of pathologists or horticulturists into whose hands such material might be referred. Obviously, the only means of ascertaining the distribution of the disease is through surveys by competent inspectors thoroughly familiar with the characters of the phony disease in the field.

The approximate date of introduction of the phony disease may frequently be determined by a comparison between the size of the phony tree and that of normal trees of the same age, and by an examination of terminal twig growth of recent years. In the majority of cases it has been evident that the introduction of the disease over the vast territory outside of Georgia that it is now known to occupy has taken place approximately within the last decade. Instances have been few in which an introduction is possibly of longer standing. An outbreak comparable to that described in Georgia would undoubtedly have come to light had one ever occurred in another section, and in such a district there would now be larger colonies than have yet been found in the outlying territory. It therefore appears safe to assume that the principal if not the entire dissemination of the phony disease as shown in Figure 5 may have emanated by one or another means from the original colony in Georgia.

Centers of recent introduction of the phony disease have been located in 12 States other than Georgia; namely, Alabama, Mississippi, Florida, North Carolina, South Carolina, Tennessee, Illinois, Louisiana, Arkansas, Texas, Oklahoma, and Missouri (Fig. 5.) It is significant that these new centers of the disease are scattered and that the percentage of phony trees is relatively very small. Prompt eradication in the incipiency of new and extended distribution is important, otherwise the disease will spread from the new centers and control will become a formidable undertaking.

When it was discovered that the cause of the phony disease is attributable to a virus that is confined to the roots of the diseased

trees, a search was made for rootstocks that would be suitable for propagation and culture of the peach and at the same time resistant to the virus of the disease or to natural infection. Roots of several species of the peach and of its close relatives (plum, apricot, almond, and others) are under trial, but as yet such work has yielded no results of practical value in control of the phony disease. Obviously, this phase of the investigations is designed to affect future plantings and could have no bearing on the protection of the millions of peach trees in present orchards.

AIDS TO IDENTIFICATION

Tree as a Whole

The phony tree is most easily recognized when in full foliage and in prime vigor. With the onset of visible characters of the disease a phony tree develops shortened internodes, a large number of lateral twigs, and flattened dark-green leaves, giving the appearance of compact, dense growth with luxuriant foliage. Decided dwarfing results and is especially prominent in young trees.

Identification is greatly facilitated by conditions ordinarily met with in cultivated commercial orchards where diseased trees may be compared with normal trees of the same age and the same variety and where care of the trees is uniform.

For the most characteristic effect the observer should turn his back to the sun and view the tree as a whole from a distance of several yards. The phony tree tends to present a more or less uninterrupted green area of fairly even outline against the sky, and to cast a strong shadow on the ground (Figs. 6 and 7), whereas an adjacent normal tree exhibits elongated terminal shoots often interspersed with long streaks or with patches of sky, and casts a lighter shadow. (Fig. 8).

Viewed en masse and from a distance, the foliage of a markedly phony tree presents a striking depth and richness of green color that is further enhanced by a vivid and unusual luster. The contrast between the phony and the normal foliage may lose much of its sharpness upon closer examination, but the explanation of the difference between the two then becomes apparent.

Actually, for trees of the same age and the same variety, and for similar growing conditions, the phony tree has fewer leaves than the normal tree. (Fig. 9.) This is attributable to the marked dwarfing effect of the disease, which results in shorter twigs and fewer leaf buds per tree. However, the shorter internodes of the phony twigs appress the leaves so that they lie closer together; the increased number of leafy lateral branches and twigs causes the display of more leaf surface per unit of area at the exterior portion of the foliage mass; a larger percentage of the individual phony leaves are straight or only slightly curved along the midrib, and the leaf blades are mostly flat or nearly so; the flattish or slightly folded deep-green leaves extend to or nearly

Figure 6.—Phony peach tree, Elberta variety, 6 years old, representing a new positive case of the disease. (Photographed at Fort Valley, Ga., August, 1921)

Figure 7.—Phony peach tree, Elberta variety, representing an old case of the disease. (Photographed at Ridge Spring, S. C., July, 1930)

Figure 8.—Normal peach tree, Elberta variety, 6 years old, in the same orchard as the phony tree shown in Figure 6. (Photographed at Fort Valley, Ga., August, 1921)

Figure 9.—Entire leaf crops from phony and normal peach trees compared: A, From a phony peach tree 7 years old having shown phony characters about 4 years; B, from a normal tree 7 years old in the same orchard. (Photographed at Fort Valley, Ga., September, 1926)

to the terminal buds of the current year's growth; as a result of the peculiar profusion of short lateral branches and twigs the disposition or arrangement of the leaves is such that a preponderance of the flat upper leaf-surfaces are exposed more or less perpendicularly to the eye of the observer, thus giving the full effect of the deep-green underlying cells, which is enlivened by a gloss from the smooth epidermal tissues. In comparison, normal leaves are of a lighter shade of green and are farther apart along the twigs, also, a greater number of the normal leaves are curled and show leaf blades that are folded along the midrib, thus exposing more of the lower leaf-surface, which is whitish and has no gloss.

Under the ideal conditions just pictured, where vigorously grown trees of the same age and the same variety are in full foliage and where the observer has the advantage of comparing the phony tree with adjacent normal trees in the same orchard, identification of advanced stages of the phony disease is not difficult and no further aids may be necessary. The diseased trees may be recognized with ease by an experienced observer even as he rides past an orchard on a railway train or in an automobile.

Field identification of the phony disease under circumstances less favorable than those described above requires much more experience with the disease and its manifestations under a wide variety of conditions.

Incipient stages of a disease frequently present the greatest difficulties in diagnosis, and this is especially the case with the phony disease, as the observer must be guided by relatively slight changes in characters of apparently healthy growth, characters so obscure that they must be determined from the general aspect of the entire tree as viewed from a distance and are totally lost in detached specimens. Trees in which the disease is just emerging from the incubation period may therefore be very confusing, even under conditions otherwise ideal for identification. However, on familiar ground and after long practice, a competent inspector may be about 98 per cent correct in his identifications of phony trees that are just a shade off normal and that are not yet sufficiently diseased to attract the attention of a less experienced observer. Detection of early stages of the disease is important for efficiency in eradication work.

Identification of the disease in poorly cultivated or abandoned orchards, in trees suffering from winter injuries or other physiological diseases of a constitutional nature, in trees that are weak or "stagnant" (lacking vigor) for any cause, in home orchards of mixed varieties, in wild peach seedlings, in trees of different ages and under different ecological conditions, requires experience and practice. No brief written description is adequate to cover the subject.

Phony trees do not seem to be more subject to winter injuries or to other serious tree-weakening diseases than are normal trees, and they may live many years after showing characters of the

disease. However, since the terminal growth is short and can not be materially forced, it is difficult to shape the phony tree by pruning to stimulate new growth, and as large limbs die or are broken down they are not replaced by the tree. After several years of the disease, the trees are usually ragged, and there is apt to be a notable dying-back of terminal twigs and branches. Nevertheless, growth characters and seasonal behavior remain typical of the disease, even in the case of trees that may have only one or two live branches left. As long as there is life in the phony tree, however mutilated the latter may be from mechanical injuries and weakening influences, the foliage tends to be characteristic of the disease and to be greener and flatter than the foliage of normal trees in a similar weakened condition.

Rarely does one limb or one side of a well-balanced phony tree show accentuated symptoms of the disease in advance of other parts of the same tree; as a rule all the branches develop phony characters simultaneously and in about equal intensity. Exceptions can usually be traced to injuries or other disadvantages that impair growth on one side of a tree, or to favorable influences that bring about a stimulation of growth in only one part of a tree, the latter case being illustrated in poor orchard trees that are situated in a road row or are adjacent to a cultivated and fertilized field. In such examples as these the more vigorous parts of the tree may show definite phony characters before the disease can be detected in the impoverished limbs. In doubtful cases it is always advisable to view in turn all sides of the tree.

Cultural Practices

So great an aid is vigorous growth in the identification of phony trees, that good cultural practices may be employed in hastening the development of sharp contrast between the phony and the normal trees in an orchard. Such methods are of particular importance in facilitating the detection of new cases of the disease in trees that are more or less stagnant. Extreme measures need not be resorted to, but the trees should be pruned, fertilized, and cultivated, in keeping with methods commonly employed in the best commercial orchards. All phony trees that have passed the incubation period will become conspicuous under such treatment and may be easily identified. The effect of severe pruning in bringing out definite phony growth-characters in a doubtful stagnant tree is shown in Figure 10.

Seasonal Aids

Characters and behavior exhibited by the phony tree at different seasons of the year also have important diagnostic values.

Figure 10.—A phony peach tree of the Hiley variety, 6 years old, showing the effect of severe pruning. This tree lacked vigor, and while it appeared to be phony, identification of the disease was difficult. Of the framework limbs, two were severely pruned in December, 1924, and one was left unpruned. In the spring of 1925 accentuated phony growth characters appeared in the part of the tree that had been forced by the pruning. (Photographed at Fort Valley, Ga., April, 1925)

Winter: In the dormant condition and before annual pruning has been performed, well-marked cases of the phony disease in orchards may be identified in districts where the disease is known to occur. The phony trees are dwarfed and show short terminal and short lateral twigs, short internodes, and profuse lateral branching from growth that has been produced since the tree developed symptoms of the disease. The appearance of the trees in the dormant condition should not be relied on for positive identification of the disease in territories not known to be infested, without recourse to the laboratory test, presently to be described.

Spring: The termination of the rest period is hastened by the phony disease. For a given variety and under similar orchard conditions, the flower and leaf buds of a phony tree usually start growing a few days earlier than those of a normal tree. The phony tree will customarily pass the blooming period and show very advanced foliage before the normal trees have dropped their petals (Fig. 11); for a period of about ten days the phony trees are easily identified by this character. Normal trees will then overtake the phony trees in leaf development, and for about two or three weeks identification becomes difficult in trees that have not had the disease a long time and that are of approximately

the same size as normal trees. Normal shoots will then begin to exceed phony shoots in length of new growth, and thereafter it becomes easier to make identifications on the basis of the current season's growth characters.

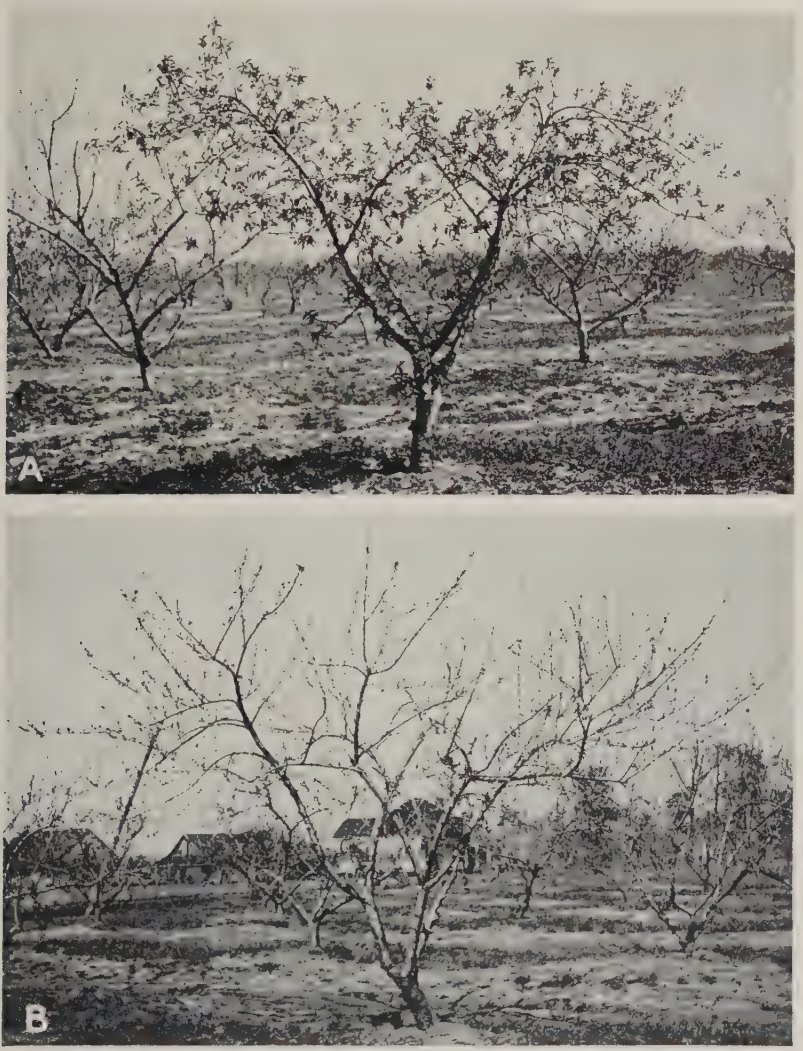

Figure 11.—Early foliation of a phony peach tree (A), as compared with a normal tree (B), both of the Elberta variety and in the same orchard. (Photographed at Fort Valley, Ga., March 23, 1922)

During the blooming period the massing of flowers along the numerous short twigs of the profusely branched phony tree presents a strong contrast to the appearance of a normal tree in flower, unless pruning has been severe.

Summer: In addition to the advantage of making inspections when the trees have completed a large part of the season's growth and are in full foliage, an exceedingly valuable confirmatory aid to identification may be furnished by the unpicked fruit at harvest time. In orchards where the phony trees may be compared with normal trees of the same age and the same variety, phony peaches will average decidedly smaller than normal peaches, and ripen a few days earlier. These are constant characters of the disease wherever it is known to occur.

Fall: New cases may emerge from the incubation stage of the disease in late August and in September, and trees that appeared normal in midsummer may be typically phony before leaf fall. Phony trees tend to hold their leaves several days longer than do normal trees and may be in nearly full foliage for a considerable period after normal trees are defoliated. (Fig. 12.) An exception should be made here for trees that have suffered from spray burn or from other defoliating influences.

Figure 12.—Peach nursery trees, Elberta variety, of same age; two phony trees in the center are holding their foliage several days longer than the normal trees to the left and right. The trees were propagated by the piece-root grafting method, root pieces pruned from an orchard tree in the incubation stage of the phony disease being used. About 50 per cent of the resulting nursery trees developed the disease. For discussion, see experiments of series C, page 44. (Photographed at Fort Valley, Ga., October 24, 1931)

Miscellaneous Characters

Fruit: No constant, pronounced differences have been observed that may be relied on as a criterion for distinguishing phony from normal peaches after they have been harvested from the trees. Individual fruits from phony trees are small, but for their size are fairly typical specimens of the horticultural variety to which the tree belongs. They may be distinctly poorer in flavor than normal fruit, though slightly better in color. In the varieties that normally produce elongated, flattish fruits with a prominent lip, phony peaches sometimes show a tendency to approach more closely a spherical shape when ripe than do normal peaches. It is not unusual for the average size (volume) of normal fruits to be about two and one-half times that of diseased fruits. The ripening of phony fruit of a given variety will begin a few days earlier than that of normal fruit in the same orchard and may extend over a period of a week or 10 days. As the normal fruit begins to ripen there is a short period during which both classes are being harvested and may be mixed in the picking baskets. For phony as well as for normal fruits there may be a considerable size variation among individual specimens. In sizing, few if any of the phony fruits will fall in Fancy or No. 1 grades, a certain number may fall in the lower commercial grades, and the majority will fall in the culls, as too small to ship. Such phony fruits as may find their way into commercial packages containing normal fruits of the same grade lose their identity, and present no markedly distinguishable differences from the normal.

Leaves: In a composite group attached to the tree, phony leaves through their characters and arrangement offer an excellent aid to identification of the disease, but in detached specimens of leafy twigs and branches this value may be partly or totally lost, because in normal trees it is sometimes possible to find a certain number of leafy twigs and branches that closely resemble similar specimens that may be selected from phony trees. With detached specimens, if it is known that one branch is normal and another is phony, recognition of the diseased specimen may not be difficult; but when dealing with unknowns, definite identification of the phony disease on the basis of macroscopic or general appearance of detached specimens should not be attempted.

As a class, phony leaves are several shades deeper green than are average normal leaves of the same variety, and this is almost universally true where the phony and the normal trees are under similar orchard treatment. However, if leaves from a phony tree weakened by poor cultural conditions or by another disease be compared with leaves from a healthy and heavily fertilized normal tree, it may be found that the usual color relation between the two is reversed. In some instances phony leaves are smaller than normal leaves, but in other instances they may be as large as or larger than normal leaves. The straight midrib and the

flat blade of the typical phony leaf often make it possible to lay the leaf on paper in such a way that a satisfactory marginal outline may be traced with a pencil, whereas this is usually not possible with normal peach leaves, because the latter are likely to be much folded, wrinkled, and curved.

Seeds: No means is known for identifying the phony disease in seeds from a phony tree. For the same variety and orchard, phony seeds will average smaller in size than normal seeds, but this is the only difference that has been observed between the two classes, and it is not sufficiently marked to be of accurate diagnostic value. In the commercial varieties phony seeds are seldom as small as the "Tennessee natural" seeds in common use by nurserymen. Except in phony fruit of very small sizes, the flesh is usually reduced proportionately more than the seed on account of the disease. (Fig. 13.) Phony seeds have well-formed kernels and give excellent germination, producing seedlings that are normal and that inherit no predisposition to the disease.

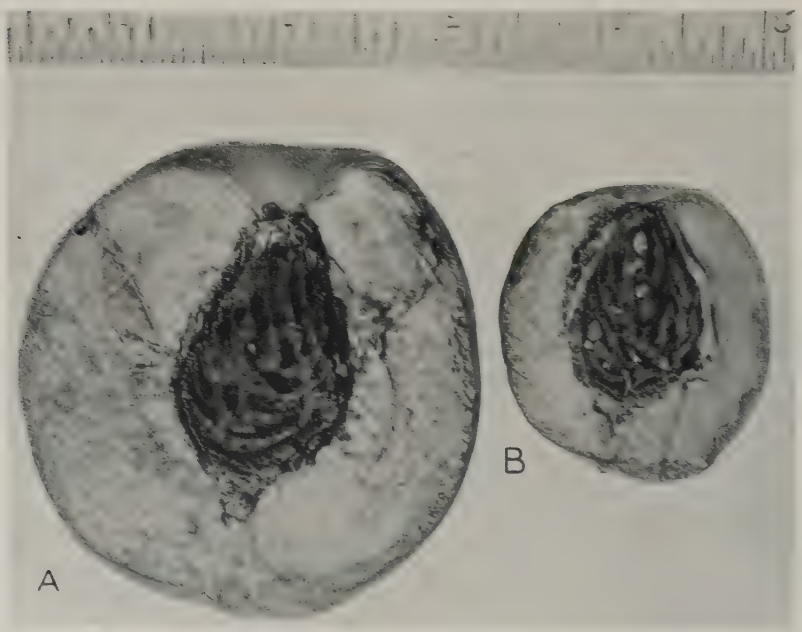

Figure 13.—Longitudinal sections of Elberta peaches, showing the seeds of normal (A) and phony (B) fruits. (Photographed at Fort Valley, Ga., August 1, 1931)

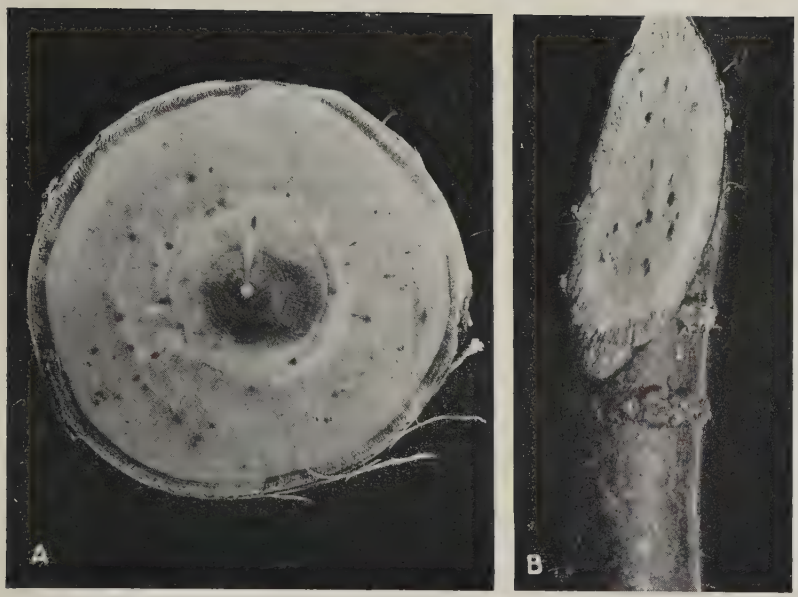

Figure 14.—Flecks in peach wood, common in old cases of the phony disease. A, Limb wood; B, root wood. (Photographed at Fort Valley, Ga., March 7, 1931)

Roots: The macroscopic appearance of the individual uncut roots or of the entire root system of the phony tree is in no way indicative of the presence of the virus in the inner tissues. Even where the disease is of long standing in the tree, it has not been possible to distinguish phony from normal roots by growth characters or by an examination of the bark.

Flecks in root and limb wood: It is not uncommon to find well distributed brown streaks running lengthwise throughout a large part of the woody cylinder of a phony tree in which the disease is very pronounced or of long standing. In transverse sections of the woody cylinder the cut ends of these streaks appear as spots or flecks. (Fig. 14.) Flecks in the wood are apt to be more abundant in sections from roots than in those from limbs. Such discoloration of these tissues is undoubtedly a secondary symptom of the phony disease, but is unreliable as a positive diagnostic character, in that the flecks may or may not be present and that almost identical symptoms, both in phony and in normal wood, may be traced to other causes, notably to mechanical injuries.

Branches, twigs, and succulent growth: The profuse development of small lateral branches and twigs, frequently referred to, for the most part takes place from the elongating new shoots of

each current year, beginning with, and following the appearance of the disease in the tree. Growth older than this, whether produced before or after the tree became phony, does not show an abnormal tendency to push succulent new shoots unless stimulated to do so by severe pruning or its equivalent, such as the breaking down or death of prominent outer limbs. The disease in itself does not stimulate the production of an abnormal number of suckers or water sprouts from any part of the tree. Apart from the direct influence of the disease, the annual terminal twig growth of the phony tree varies considerably with such factors as the age of the tree, pruning, general vigor, and the environmental complex in which the tree is grown. Under orchard conditions it is usual for the pronounced phony tree to produce an annual terminal growth of 1 to 6 inches, as compared with a terminal growth of 1 to 3 feet or more in normal trees.

Difficulties, Varietal and Seasonal

Positive identification of the phony disease in brachytic,* in weeping, and in certain other ornamental types of peach trees may be exceedingly difficult or even impossible without recourse to inoculation experiments or to the laboratory test, and the latter test should be employed where trees of this description are undergoing inspection. When artificially inoculated dwarfs of the above-named types are compared with uninoculated checks of the same species or the same horticultural varieties, it has been found that the dwarf character is slightly but definitely accentuated on account of the phony disease, and that changed seasonal behavior (advanced flowering and leafing, and retarded leaf fall) is as pronounced as in the case of phony trees of the commercial peach varieties. If their characters and seasonal response throughout the year are taken into account, therefore, the natural dwarfs are not truly symptomless carriers of the infective virus of the phony disease although they may virtually attain such a status unless it is possible to compare them with known normals of their respective horticultural varieties.

It has not been observed that phony leaves as a class are markedly different from normal leaves in susceptibility or resistance to leaf parasites; but, other conditions being comparable, it has been noted in Georgia that phony leaves are somewhat more susceptible to injury from the usual orchard sprays than are normal leaves. Partial premature defoliation, together with pronounced leaf injuries, on account of spray burn, are occasionally met with in phony trees of that section, after midsummer.

"Silvering" of peach leaves, caused by mites of the genus Phyllocoptes, has frequently been observed in Georgia orchards, in late summer and fall; and when severe, it may appreciably obscure some of the usual leaf characters of phony trees.

*A dwarf type with extremely short internodes and very large flattish leaves.

Phony Characters in Species Other than Peach

As will appear in the following chapter, it has been proved that several species closely related to peach (plum, apricot, almond, and others) may be made to contract the phony disease through the medium of artificial inoculation, and that all of these sorts upon becoming phony develop dwarfed growth and changed seasonal response, for the most part in close imitation of the phony peach tree.

Summary of Phony Characters

From the foregoing discussion, it is apparent that the phony disease presents relatively few of the symptoms which, individually or severally, are often associated with a diseased condition in peach trees. The disease does not induce spindling growth or rosetting, it does not cause yellowing, rolling, or spotting of the leaves, and it does not produce lesions, malformations, or discolorations, in the nature of cankers, galls, hypertrophies, or spotting or streaking of leaf, fruit, twig, limb, trunk, or root. Instead, the phony tree displays rich deep-green leaves, smooth bark, and much-dwarfed but otherwise healthy appearing fruit. Dwarfing of the tree, the aspect of the tree in leaf, small fruit, crop reduction, and certain marked seasonal behavior, constitute the principal departures of the phony tree from the normal.

LABORATORY IDENTIFICATION TEST

A valuable confirmatory aid to identification of the phony disease has been furnished through the discovery of a simple and rapid test applied to transverse sections of root wood of a suspected tree. (Fig. 15.)

Selection and preparation of specimens to be tested: Entire root pieces from 4 to 6 inches long and of such size that the woody cylinder measures from one-half to three-fourths inch in diameter are convenient and reliable for the test, although smaller roots may be used. Obtain one or more such pieces from each of four sides of the tree. The specimens should be clean and healthy in appearance (uncut phony roots are indistinguishable from normal roots), free from scars, galls, or dead areas (as these may cause the test to be obscured), and remote from any malformations or injuries in the root branches from which the selections are made. Do not bruise or strain the roots in cutting them from the tree. Make a clean cut across the ends of each root piece, to permit examination of the wood, which for a satisfactory test should be white or nearly so, fresh, and in good condition throughout. The bark should be firmly attached to the woody cylinder, except at the cut ends, to avoid discoloration of the wood by oxidation. Wash the roots, remove excess water, and test at once, or wrap in waxed paper to prevent drying out. Specimens so prepared may usually be kept a few days without impairing the quality of the test.

Apply the test to one root piece at a time. Cut a half inch or more from the ends in order to eliminate discolored tissues, remove the bark for a distance of three-fourths inch from the freshly cut ends, cut with a sharp knife entire transverse sections of the woody cylinder, from one-half to 1 mm thick, and immerse the sections immediately in the test reagent. Discard sections that crumple or break or that show traces from branch rootlets. Except as noted hereinafter, discard all roots in which the woody cylinder shows any dead or discolored spots whatsoever.

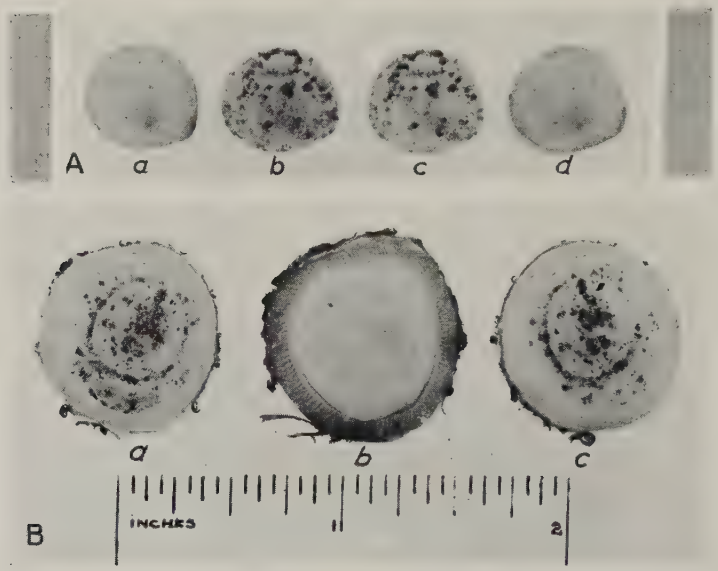

Figure 15.—Laboratory identification test for the phony disease. A, Transverse serial sections of the woody cylinder of a phony peach root: **a** and **d**, Sections before test; **b** and **c**, sections after test. B, Transverse serial sections of an entire phony peach root, showing that the characteristic spots appear in the wood and not in the bark: **b**, Before test; **a** and **c**, after test. (Photographed at Fort Valley, Ga., April 30, 1932)

Preparation and use of the test reagent: Acidulate absolute methyl alcohol by adding 1 to 5 drops of a concentrated, chemically pure, solution of hydrochloric acid to each 25 cc of alcohol. The proper degree of acidity is important and varies somewhat with the specimens. Acidulation should ordinarily be such that the test-time is 3 to 5 minutes. Two or 3 drops of acid per 25 cc of alcohol generally makes a satisfactory test-reagent and may be kept as a stock solution to be used as needed, without dilution. For the test, on a white background, and in good light, set up a series of flat-bottom watch glasses (Syracuse type), each glass containing about 5 cc of the test-reagent. Use a separate watch

glass for each root piece, and from the latter cut and test 4 or 5 sections from each end, in turn. Discard the used reagent after each group of sections is tested.

Interpretation of the test: After the transverse sections of root wood have remained in the test-reagent for a few minutes, a positive test for the phony disease is indicated when numerous well-distributed purplish spots, plainly visible to the naked eye, appear in the wood. The spots may vary in size from points to areas about 2 mm in diameter, and they may vary greatly in number. For each section, at the conclusion of a positive test, from 10 to 50 or more spots, very definite, intensely colored, and distributed over the entire surface, must stand out in sharp contrast against a clear background of whitish or faintly tinted (purple or lavender) wood. Check tests may be made on sections from known normal roots. At the end of the test-time for phony root sections the normal section should still be free from color, or should show a fairly even purple tint with no tendency to localization in well-distributed, intensely colored spots. Thinner portions of sections will be the first to color; the reaction of the pith and the rays is somewhat variable but in no way confuses the test. If acidulation be too strong, or if sections be allowed to remain too long in the test-reagent, the entire surface of the sections (either normal or phony) may display a purple color.

In a well-developed case of the phony disease it is usual for every suitable root to give a good positive test. Very often it is possible to obtain a conclusive positive test from some roots of a phony tree before the latter has completely emerged from the incubation period of the disease. A positive determination for the phony disease should not be given unless all conditions are perfect for the reading, as described above. The test may be applied throughout the year. Carefully performed, it has been of reliable diagnostic value in confirming field identifications in each of the 13 States where the phony disease is known to occur.

In old cases of the phony disease, flecks in the nature of faintly-discernible to definitely-brown spots may appear in the wood, and it may be difficult to find root pieces free from them. (Fig. 14.) When such specimens are given the laboratory test, if they are from a phony tree the visible spots develop a purple color and their number will be increased by a large number of new spots that were invisible to the naked eye before the test was applied. If there is no choice but to work with specimens showing flecks, caution and experience may be required to interpret the test correctly.

RESEARCHES INTO THE CAUSE OF THE PHONY DISEASE

Complete presentation of the technical investigations on the phony disease that have been carried out or that are in progress, at the U. S. Peach Disease Field Laboratory, Fort Valley, Georgia, is beyond the scope of this bulletin. The present account will be limited to (1) some of the preliminary investigations that corroborated or disproved popular notions and that have a practical bearing on peach culture in relation to the phony disease, and (2) certain key experiments that finally revealed the interesting story of the cause of this strange malady.

Preliminary Investigations

Records indicated that the distribution of the disease was not narrowly limited by ecological factors and that it could not be attributed to a soil condition. It is found on washed mountain sides and in fertile valleys, on land newly cleared from the forest and on old cultivated fields. It occurs on all soil types within its range, on land not previously planted to peach trees, and is independent of cultivation, drainage, drought, cover crops, and animal or chemical fertilizers. Pruning, fertilizers, and cultivation only accentuate the characters of the disease and thereby greatly facilitate identification. They may bring out the characters in a stagnant phony tree (Fig. 10.), but in no case do they directly cause the disease. When the research was undertaken, in 1921, there was a strong popular belief that the phony disease was much more prevalent near barns and where stable manure and other highly nitrogenous fertilizers had been applied to the land. It was soon discovered that in well-fertilized trees the characters of the disease are so pronounced as forcibly to attract attention, and that the casual observer overlooks definitely positive but less conspicuous cases scattered over the portions of a planting that are less favorably situated for luxuriant growth.

Orchard records showed that once a tree had contracted the disease it never recovered, neither did it die of the disease. Transplanted phony trees remained phony. When phony trees were dug out and replants were immediately planted in the holes, the replants remained normal, except for a certain number that corresponded with the usual incidence for new cases of the disease in the orchard in question. Normal nursery trees planted under the branches of phony trees did not contract the disease but worked their way through the branches of the dwarfed phony trees and overshadowed them. It was thus indicated that the disease is not communicated by contact and that it is not usually, if ever, communicated through the medium of the soil. This appeared to eliminate nemas, mychorriza, and other soil organisms as possible causal agents or vectors of the disease.

That, in so far as the soil is concerned, it is entirely safe to replant an orchard site immediately following the removal of phony trees was later proved under most severe conditions. A 12-acre

block of Elberta trees, 99 per cent of which were phony, was removed and immediately followed by a new planting of nursery trees from phony-free territory in a distant State. Live phony rootlets extended abundantly into the holes in which the nursery trees were placed, these being located in the centers of the squares formed by the location of trees in the old orchard. The new orchard is now (1933) in its sixth year. Very few cases of the phony disease have appeared in this block of trees and such cases can be accounted for on the basis of causes other than the soil.

Not only was the block of trees in the above experiment planted immediately after the removal of an old orchard in which 99 per cent of the trees were phony, but it is the fourth planting to occupy the same site in less than 40 years, one orchard succeeding another without resting the land. The fact that this most recent planting is remarkably free from the phony disease disproves also a once-popular theory that trees are more subject to the disease when grown on land long planted to peach trees.

The possibility that the disease might be seed borne was given a thorough trial. In different years large numbers of seeds from typical phony trees were planted. Excellent germination was always obtained, and the seedlings grew normally in every respect. More than 1,000 seedlings from phony seeds were budded to a commercial variety, and an orchard block of 12 acres was planted with these specially propagated trees. Neither in the nursery, where thousands of the original seedlings are still standing, nor in the orchard trees propagated on understocks that developed from phony seeds, has there been the slightest evidence that trees originating from phony seeds are predisposed to the disease. Local canning-factory seeds are therefore safe, and there is no danger of introducing the disease into new territory through shipments of fruit containing phony peaches.

An attempt was made to determine whether there might be a predisposition to the disease in certain nursery trees, and to compare relative susceptibility in nursery stocks from widely different sources. Buds from the same normal tree, for each of three varieties, were sent to well-known nurseries in a western, a southern, and an eastern State. The bud sticks bore numbers instead of variety names in order to avoid accidental substitution. Seedling peach trees in the respective nurseries were then June budded in accordance with instructions and the following winter the nursery trees, in numbered lots, were in each case shipped to the Fort Valley laboratory. For 3 varieties, then, there were nursery trees in which the top growth originated from buds selected from an identical normal Fort Valley tree, and in which the peach-root understocks were of the sort customarily used in the respective western, southern, and eastern nurseries. Elberta was chosen as the variety to be used in an orchard test, and the trees were selected by the number used to designate this variety on the records. Supplementing the specially propagated trees, additional Elberta trees were secured from the regular home-grown commercial stock of nurseries in Alabama, Tennessee, and Maryland. A 12-acre orchard block was planted at Fort Valley,

in which not less than 120 trees from each of the 6 States were used. All the trees came true to the Elberta variety and it was thus certain that the special propagation had been correctly handled by the nurseries that kindly cooperated in the work.

This exceedingly interesting orchard displayed some variation in growth rates of trees from one State as compared with those from another, but after a year or so the differences were no longer observable. During the third summer after the orchard was planted a few trees developed symptoms of the phony disease, as would naturally be expected in the infested territory. The disease increased all over the orchard, as the years went on, but it was never possible to note any differences in susceptibility based on origin or special propagation of the nursery trees. It was concluded from this experiment that the source of commercial peach nursery trees, propagated on the usual peach-root understocks and grown in phony-free territory, has no appreciable bearing on relative susceptibility or resistance to the phony disease.

In a series of experiments carried out in summer, juices expressed from different organs of phony trees were injected into normal trees. Juice infusions and crushed tissues were introduced into the roots, trunks, and branches of experimental trees. Through several years the trees so treated remained normal.

Frequent microscopic examinations were made, and laboratory cultures from living tissues of phony trees were prepared in different years. A large range of culture media was employed, but all cultures remained sterile, with the exception of the rare occurrence of common contaminations. The disease was apparently not due to a visible parasite.

Species other than peach when budded or scion grafted on phony peach trees developed growth characters typical of the phony disease. This was true in experiments where Peento and Honey peach types, *Amygdalus davidiana,* and commercial varieties of almond, apricot, and nectarine were top-worked on phony trees. The dwarfing effect was particularly striking in the case of *A. davidiana.* Growth of this species when grafted on a normal peach tree was in some cases 10 feet in one season, as compared with a bushy, profusely branched growth of 18 inches on a phony tree.

One hundred peach seedlings were budded with Elberta buds from the most severe cases of the phony disease that could be found. The buds were forced in the usual manner, and the following winter the trees were planted out in orchard formation beside 100 check trees propagated from the same nursery lot of seedlings, but in which Elberta buds from normal trees were used. The phony-budded nursery trees developed into fine, normal Elberta orchard trees, equal in every respect to the checks that had been grown from normal buds. Furthermore, in every case where individual buds from phony trees had been budded on normal orchard trees, the outgrowth from the phony bud itself was entirely normal, and the disease was not transmitted to the healthy tree. Similarly, when scions instead of buds were used,

the resulting growth was normal, and the disease was not communicated. These experiments established the fact that no infective principle of the disease is carried in the buds or scions and that the disease does not partake of the nature of a bud sport or a genetic disorder.

Orchard surveys seemed to indicate that under the most favorable conditions for its appearance a very small percentage of the trees did not take the phony disease, and it was thought that in some way these trees might be resistant. However, when scions or buds were selected from such normal trees and top-worked on phony trees, the new shoots that put out were always typically phony. On the other hand, when buds or scions from phony trees were top-worked on these same normal trees, the resultant growth was always normal. Therefore, if such normal trees possessed any resistance to the disease, it could not be attributed to a character of the buds or scions.

The fact had been repeatedly established in a variety of experiments that the dwarfing effect in the top growth of phony trees is only a symptom and secondary, and that the cause must be a condition in the root system of diseased trees. All attempts to associate the disease with external conditions had failed. It remained to investigate internal conditions of the roots themselves. There was a possibility that the normal physiology of the root system became disturbed in some obscure manner, that somehow a toxiclike substance might be supplied to the sap stream, and that this caused the dwarfed growth and deep-green foliage of the phony tree. On the other hand, there was a possibility that the phony roots supplied sap lacking in some ingredient essential to normal growth of the shoot. More intriguing than either of these theories was the theory supported by the increasing evidence from general observations and surveys, that the disease must be of a contagious nature. The population of phony trees in the central Georgia area was constantly increasing; old trees and young alike were contracting the disease in alarming numbers; new outposts were being discovered; in a large colony movement the disease was marching outward into previously phony-free territory.

In order to test the theory of a noninfectious, physiological disturbance or degeneration in the roots of trees developing phony characters, an attempt was made to induce partial or complete recovery from the disease. Phony orchard trees were severely root pruned in midwinter. Roots measuring 1 foot or more in length and from three-fourths to 1½ inches in diameter were cut from normal orchard trees and grafted to 10 or more well-distributed roots of individual phony trees. In other cases several vigorous nursery trees of peach and of other species were laid horizontally in the soil about phony trees and graft unions were made between the collars of the nursery trees and phony-tree roots of the same size. The graft unions were successful, and the normal-root grafts flourished in the soil, but the sap stream was not sufficiently altered to change the character of twig and

leaf growth, and phony trees so treated gave no response indicating even partial recovery from the disease.

During the first five years of this research, many facts had been obtained concerning the history, spread, and economic importance of the phony disease. Its characters came to be well known, as did many points concerning its behavior. But all experiments designed to determine the cause of the disease and whether it might be infectious had given negative results. Its distribution did not appear to be limited by geographical, climatic, or soil factors, and it could neither be caused nor cured by pruning, fertilizers, cultivation, or cover crops. Transplanted phony trees did not recover. Replants immediately following phony trees did not contract the disease, and the phenomenon was not due to a "soil sickness" or to soil organisms. It could not be attributed to degeneration of nursery stocks. Juices from different organs of phony trees failed to introduce the disease when injected into normal trees. Microscopic examination and laboratory cultures failed to show a fungous or bacterial parasite in any living tissues of phony trees. Healthy, normal trees developed from phony seeds. Normal buds and scions of peach and of closely related species developed typically phony growth when top-worked on phony trees, whereas buds and scions from phony trees developed normal growth when top-worked on a normal tree. No infective principle was carried in buds or scions, and the disease did not partake of the nature of a bud sport or a genetic disorder. But the condition was rapidly increasing in local orchards and was spreading to previously nonphony territory. Trees were contracting the disease at the end of the second year in the orchard or in any year thereafter, and once phony, they never recovered.

The phony trees had guarded well their secret. They had answered "no" to all observational and experimental inquiries seeking the cause of the disease and this latter subject had not been approached in any satisfactory manner. However, one important premise for future investigational work had been established, namely, that the disease must be attributable to some internal condition of the root system of the phony tree. With this background as a guide, a new line of attack was organized.

Infectious Nature of the Phony Disease

Beginning in 1921, certain peach orchards in the vicinity of Fort Valley, Georgia, were charted one or more times annually, and the phony condition or the normal appearance of each tree was recorded for each observation. Over a period of 11 years, records of this kind included never less than 10,000 individual trees per year, and for a few years the number ran as high as 35,000 trees. As old orchards were destroyed, new plantings were substituted on the charts. The progress of the phony disease over old and new plantings was closely followed, and a wealth of information concerning the disease was obtained. For several thousand individual phony trees in these orchards the first ap-

pearance of the disease and its subsequent course were known. Pertinent to the discussion presented in the following paragraphs are the indisputable facts learned from these extensive records, that during the period covered, an orchard peach tree in this territory might develop phony characters during the latter part of the second growing season or in any year thereafter, and that once phony, the tree never recovered. It should be remarked that the universal practice in this territory has been to plant peach trees propagated on peach-root understocks in common use by nurserymen.

Later Experiments

Experiments presently to be described were first performed in January of 1925, 1926, or 1927, and all have been repeated in at least three different years (unless otherwise noted), with no variation in the results. For convenience in the discussion, the experiments are grouped in series, the latter being lettered in the order of presentation.

Series A: In midwinter several phony orchard trees and several normal orchard trees were dug in such a manner that for each tree the collar was removed and with it all roots out to a line defined by a circle the center of which was in the location where the collar had rested and the radius of which measured about 3 feet. The remainder of the root system was left undisturbed in the soil. To the cut end of each suitable root (10 or more in number, for each tree) was then grafted either a normal scion or a normal nursery tree, the latter by its taproot. Within a few weeks after growth started, in the spring immediately following, it was plain that each scion or nursery tree so grafted on a phony root was developing characters of the disease, whereas each scion or nursery tree grafted on a normal root appeared normal. By the end of the first growing season after the grafting was performed, this contrast was very striking. Where a phony orchard tree had stood, disposed in a circle were now from 10 to 15 little trees, perhaps 18 inches to 2 feet high, showing accentuated phony growth characters. Where a normal orchard tree had stood, disposed in a circle were now from 10 to 15 normal trees, 6 or more feet in height. Without exception, a phony tree developed on a phony root, and a normal tree developed on a normal root. During the second growing season for the grafts, the contrast between the phony and the normal was still more accentuated.

It was indicated by these experiments that, independently of the shoot of the phony tree, phony roots were capable of producing the characters of the disease in normal shoots or in normal nursery trees grafted on such roots. The fact that, in this series, shoots grafted on phony roots developed phony characters immediately upon starting into growth instead of after a period of several months, is discussed in a later paragraph.

Series B: Phony trees were paired with normal trees, and for each pair four kinds of propagation experiments were performed

in January by the piece-root grafting method: (1) The phony tree was multiplied 50 times, root and branch, by grafting 50 scions on as many root pieces from the identical tree; (2) the normal tree was multiplied 50 times, root and branch, by grafting 50 scions on as many root pieces from the identical tree; (3) cross multiplication was made by grafting 50 phony scions on as many root pieces from the normal tree; and (4) cross multiplication was made by grafting 50 normal scions on as many root pieces from the phony tree.

The piece-root grafts, several thousand in number for the entire series, were planted in rows, where they grew into nursery trees, which latter were maintained and cultivated for several years. Throughout their first growing season these nursery trees appeared normal and were very similar, one group to another. After about 18 months from the time the grafts were propagated, however, the resultant trees could be precisely divided into two classes, based on growth characters. All nursery trees that represented propagation experiments 1 and 4 were typically phony and remained so, whereas all nursery trees that represented propagation experiments 2 and 3 were normal and remained so. Records on the subsequent behavior of the original pairs of orchard mother-trees from which the root pieces and the scions were pruned showed that the normal mother-trees remained normal for at least 18 months after the experiments were performed and that the phony mother-trees remained phony.

From the experiments of this series it was plain that either a phony or a normal scion on a phony root piece produced a phony tree, and that either a phony or a normal scion on a normal root piece produced a normal tree.

Series C: In charted orchards, certain trees, here called root-mother-trees, were root pruned (in January) in such manner as to avoid serious functional injury to the root system, but to supply from each tree 100 or more root pieces suitable for use in propagation by the piece-root grafting method. Known normal scions, uniform as to variety, were obtained from a distant source. For brevity in describing experiments of this series, a peach tree propagated by grafting a known normal scion to a root piece from one or another of the designated orchard trees under observation is called a graft. Records on the phony or the normal condition of the grafts refer to the growth characters of the latter after 18 months from the date of propagation. The experiments of this series, which extended over several years and involved more than 40,000 grafts, yielded the following data:

1. For each root-mother-tree that showed no symptoms of the phony disease 18 months after the propagation of grafts, all of the grafts were normal.

2. For each root-mother-tree that appeared normal throughout the growing season immediately preceding the propagation of grafts but that developed phony characters during the next growing season, the grafts (propagated in the intervening January) were variable, about 50 per cent being phony and the remainder being normal. (Fig. 12.)

3. For each root-mother-tree that first showed phony characters during the growing season immediately preceding the propagation of grafts, as well as for each root-mother-tree that preceding the propagation of grafts had been phony from 1 to 6 years, all of the grafts were phony.

4. For several individual root-mother-trees graft propagations were made in each of several consecutive years. For each root-mother-tree so propagated, it was shown that (a) all grafts propagated previous to or at 18 months before the root-mother-tree showed phony characters were normal; (b) of the grafts propagated in the January immediately preceding development of phony characters in the identical root-mother-tree, some were normal and some were phony; and (c) all grafts propagated after the identical root-mother-tree showed phony characters, were phony.

5. The grafts propagated as described in Experiments 1, 2, 3 and 4 of this series were maintained in good growing condition for several years. Grafts that were normal 18 months after propagation remained normal. Grafts that were phony 18 months after propagation remained phony. Root propagations were then made from a representative number of the grafts themselves, and it was found that all propagations from the roots of the phony grafts gave new grafts that were in turn phony after 18 months, whereas all propagations from the roots of the normal grafts gave new grafts that were normal after 18 months and remained so.

In the experiments of this series it was evident that preceding the appearance of phony characters in the shoot an alteration of an invisible and obscure nature took origin at some point or points in the root system and slowly progressed until each root of sufficient size for use in piece-root grafts was affected. Before this change took place in a root, the latter gave grafts that were themselves normal and of which the graft progeny was normal. After this change took place in a root the latter gave grafts that were themselves phony and of which the graft progeny was phony.

Series D: Normal nursery trees planted under the branches of a phony orchard tree displayed normal growth and worked their shoots up through the branches of the phony tree until the latter was overshadowed in cases where the root systems of the two classes were in contact but were not grafted together. In similar groups, but groups in which the root systems of the two classes were grafted together, the nursery trees, normal when planted, developed the phony disease after several months and thereafter remained dwarfs with dark-green leaves, beneath the superimposed limbs of the phony orchard tree. Normal nursery trees planted under the branches of a normal orchard tree grew normally, regardless of whether the root systems of these two groups were or were not grafted together. The subsequent behavior, normal or phony, of the nursery trees was not changed by severing their root-graft unions with the orchard tree; the normal nursery trees remained normal and the phony nursery trees remained phony.

Series E: Thirteen orchard trees, 5 years old, were transplanted from a heavily diseased block to a sparsely diseased young orchard a few miles distant. In the new location the phony trees were paired with normal trees and were planted in such manner that the branches of the phony tree of each pair in-

termingled with those of the normal tree. For three of the pairs, the phony tree and the normal were grafted together by their roots; for three, by their branches; for three, by both roots and branches; and for four pairs, the trees were not grafted together at all.

The removal of the orchard terminated the experiments at the end of two years. During the second year of the experiments, where pairs were united by root grafts only, the normals developed the disease; in pairs united by both root grafts and shoot grafts, the normals developed the disease; and in pairs united by shoot grafts only, the normals did not develop the disease.

Series F: Opportunity for a chain-graft experiment was presented by certain peach trees, 3 years old which were planted 3 feet apart in a nursery row. These trees were given serial numbers from 1 to 33. Trees 18 and 31 were phony, the others were normal. Root-graft connections were made in such manner that by their roots, trees 1 to 18, inclusive, were grafted one to another in series. No other grafts were made. Several months later tree 17 began to show phony characters, then tree 16. During the next four years the disease was observed to move a distance represented by several consecutive trees in the direction of tree 1, and to stop at a point where one of the normal trees in the chain died of winter injury. It was notable that no other trees in the experiment developed the disease during this period, and much importance was attached to the fact that although trees 19, 30, and 32 were contiguous to one or the other of the accidental phony trees (Nos. 18 and 31), in the absence of root-graft connections these normal trees remained normal.

In this and in several other chain-graft experiments the disease moved progressively from a phony tree to one after another of the normal trees in the series, but did so only under conditions where such trees were connected in sequence by living graft unions between the root systems. Severing the root-graft unions between trees of a series, thereby cutting off connection with the original phony tree of the sequence, did not bring about recovery for such trees as had already developed the disease, but it did arrest the advance of the disease along the chain.

For a chain-graft experiment in which a phony tree and several normal trees were united in series by shoot-to-shoot grafts, the normal trees remained normal.

Series G: Entire-root sections about 6 inches long were cut from the lateral roots of phony trees in midwinter and were grafted to the root systems of normal orchard trees or normal nursery trees in such a manner that each normal tree bore from one to four phony-root sections. (Figs. 16 and 17.) After a period of 18 months, nearly all of the several hundred normal trees so treated had developed the phony disease. Examination of the roots showed that in every case where the root system of the normal tree presented a successful growth union with one or more phony root pieces the normal tree had contracted the dis-

ease, and that in every case where the graft operation had been performed but no growth union had taken place between the root system of the normal tree and at least one of the phony root pieces, the normal tree had not contracted the disease.

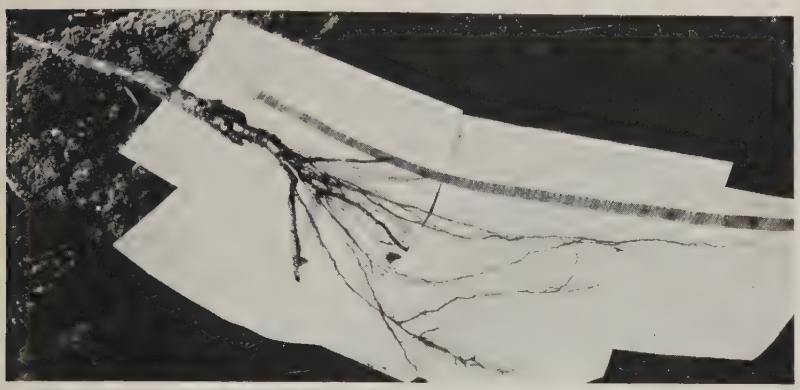

Figure 16.—Method for artificially inoculating the virus of the phony disease into a normal tree of peach or any of several closely related species. The illustration shows a phony root piece 4 inches long grafted to a root of a normal peach tree in December, 1925, together with new roots that grew from the phony root piece during 1926. The inoculated tree did not develop the disease during 1926, but was definitely phony in July, 1927, 18 months after inoculation. (Photographed at Fort Valley, Ga., December, 1926)

This line of investigation was pursued further. Each of several known normal nursery trees from a distant State free from phony disease were experimented upon in the following manner. From tree A, for example, four root pieces were cut in midwinter and immediately grafted, one root piece to the root systems of each of four known normal nursery trees, the latter lettered respectively **a**, **b**, **c**, and **d**. Tree A was then inoculated by grafting a phony root piece to its root system. Eighteen months later tree A developed the phony disease, whereas trees **a**, **b**, **c**, and **d** remained normal. The following January tree A, now phony, was again root pruned in such manner as to avoid the original phony-root piece and the latter's branches; the root pieces thus obtained were then grafted, one to the root systems of each of four additional known normal nursery trees, lettered respectively **e**, **f**, **g**, and **h**. Eighteen months after this second root pruning of tree A, the final records were taken. Tree A itself was phony; trees **a**, **b**, **c**, and **d** were normal; trees **e**, **f**, **g**, and **h** were phony. It was proved by these experiments that before a phony root piece was grafted to the root system of a known normal tree the normal tree gave root pieces that did not

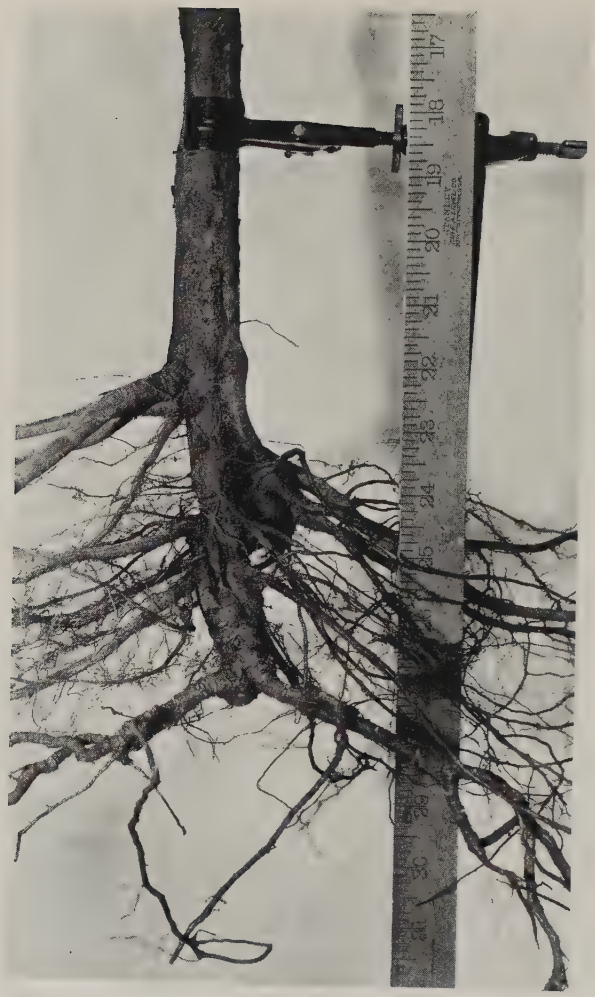

Figure 17.—Method for artificially inoculating the virus of the phony disease into a nursery tree of peach or of any closely related species. The illustration shows a root-piece 4 inches long that was cut from a phony peach tree and grafted to the taproot of a seedling nursery tree of Japanese apricot (*Prunus mume*), in February, 1930, and new roots that developed from the apricot and from the phony root piece during the growing season of 1930. The apricot nursery tree grew normally during 1930, but developed phony growth characters during 1931. (Photographed at Fort Valley, Ga., February 28, 1931)

transmit the disease, whereas after the identical tree had developed the disease as a result of inoculation this selfsame tree gave root pieces that did transmit the disease to a normal tree.

Scions from the same phony trees from which roots were taken in the root-grafting experiment were top-worked, some in phony trees and some in normal trees. In phony trees new growth that developed from the phony scions was typically phony, whereas in normal trees new growth that developed from phony scions was normal in every respect and remained so. The disease was therefore transmitted by roots but not by scions from the identical phony tree.

Series H: Entire root pieces, about 4 inches long, were cut from normal commercial peach nursery trees and grafted singly on suitable undetached branches of phony or of normal orchard trees, the root pieces and the unions being protected by wax. Only 15 of the grafts were successful, and these were divided about equally among three phony trees included in the experiment. For each of the successful grafts, however, shoots of seedling character developed from the normal root pieces; such shoots were almost immediately phony, and remained so. Scions from the respective nursery trees from which the roots were taken developed growth true to the variety (Hiley), and such growth was phony if in a phony tree and normal if in a normal tree.

In these experiments a shoot that originated directly from the tissues of a seedling root was therefore quite as susceptible to the phony disease as was a shoot that originated from a scion the line of propagation of which traced back to a seedling stem. The insertion of a normal root piece by grafting it on a shoot of a phony tree did not prevent the development of phony growth characters in shoots distal to this point.

Series I: In late winter, normal peach nursery trees from a distant phony-disease-free territory were pruned to a whip and were grafted, some in the tops of phony orchard trees and some in the tops of normal orchard trees. For each nursery tree so used, the taproot was grafted by the whip-and-tongue method to a suitable branch, the union was wrapped, and the entire nursery tree was waxed to prevent excessive evaporation. After a few weeks, when the root of the nursery tree and the branch of the orchard tree were seen to have been united by a good growth union, the wrap was removed, and a suitable container (12-quart pail) with a hole cut in its bottom, was passed down over the nursery tree until the graft union was surrounded midway of the height of the container, by the latter's walls. The container was then supported by a platform, the opening in the bottom through which the branch extended was packed with cotton batting, and the container was filled with soil, which was kept moist.

The nursery trees developed roots abundantly in the containers, and these trees thus received sap from two sources, namely, the

root system of the supporting phony tree and the nursery tree's own roots in the container. All normal nursery trees so grafted and supported in a phony tree developed growth characters typical of the phony disease, almost immediately upon emerging from dormancy, in the spring, and remained phony as long as they were thus grafted to the phony tree. The following January, 12 months after these experiments were set up, connection with the phony tree was severed at the point where the phony limb entered the container, and the container with its contents was carried to a nursery, where the little tree was transplanted to a field environment and thereafter grown for several years.

During their first vegetative season after being transplanted to the field, these trees grew out of the phony condition, became entirely normal in appearance, and thereafter remained normal.

In accordance with the method described for experiments in phony trees, check experiments were set up in which normal nursery trees were grafted to and supported by the shoots of normal orchard trees. Here, again, the nursery trees developed roots that permeated the soil of the containers, and these trees therefore received sap from their own roots as well as from the root system of the normal supporting tree. These check trees, however, developed growth characters that were at all times normal in appearance. The new shoots of the first vegetative season were from 4 to 6 feet long, in this case, as compared with new shoots that were typically phony and the length of which measured only a few inches in the case of the potted nursery trees that were grafted by the tap root to the limbs of phony orchard trees.

Proof that the phony disease is infectious

In the course of the preliminary experiments it was learned that a phony tree does not recover from the disease as a result of being top-worked with normal scions and that a normal tree does not develop the disease as a result of being top-worked with phony scions; normal scions promptly develop phony growth in a phony tree, and phony scions promptly develop normal growth in a normal tree. It was noted that regardless of whether the phony orchard trees recorded on the charts were lightly pruned, severely pruned, dehorned nearly to the trunk, or killed to the ground line by winter injury, all of the new shoot growth from the limbs or trunk and the sucker growth from the collar was at once phony in character and remained so. It seemed evident that although the symptoms of the phony disease in the field are determined by behavior and growth characters of the shoot, these symptoms were produced and maintained by the sap stream, or by a stimulus, from an abnormal or a diseased root system. This theory was further supported by the experiments of series A.

The experiments of series B showed that a piece-root graft in which the root piece came from a phony tree in turn produced a phony tree, and that the phony or the normal condition of the

scion was inconsequential. In the experiments of series C it was proved that preceding the appearance of phony characters in the shoot an altered condition of invisible and obscure nature originated at some point or points in the root system and slowly progressed until all the roots were affected.

Finally, in the experiments of series D through G, by several methods it was demonstrated that the phony disease is definitely infectious and may be communicated to a normal tree by artificial inoculation through the medium of a living graft union between a phony root or root piece and the root system of the normal tree. It is significant that in all cases in which the graft operation was performed and the fresh tissues of phony and of normal roots were pressed together and bound in close contact, but in which no growth union between the two took place, the disease was not communicated to the normal tree.

That the infective principle of the phony disease does not invade the branches of the shoot at any season of the year appears to have been conclusively proved by the experiments of series I, and this behavior would seem to account for the fact that in the course of repeated trials the disease has never been transmitted or carried by buds, scions, or seeds from phony trees.

Experiments of series H and I demonstrated that a normal root (root pieces or nursery tree) grafted on a phony shoot is unable to intercept or to neutralize the growth-retarding principle that appears to be supplied in the sap from phony roots, and doubt was cast on the possible value that it was thought this method might have as a short cut for finding resistant roots.

Classification of the phony disease in the peach yellows group of virus diseases.

Under the usual conditions of experimentation, the viruses that cause plant diseases may be classified in two groups. In one group are those viruses that for a limited or for an indefinite period may retain their active condition in juices expressed from infected tissues of the host plant, although they produce no visible growth in laboratory culture media; within a certain period after a susceptible normal plant has been properly inoculated with such juices the disease in question is reproduced. The so-called filterable viruses fall into this group. In the other group are those viruses that are totally inactive in juices expressed from infected tissues, either before or after filtration, and after a susceptible normal plant has been inoculated with such juices the disease in question is not reproduced. In some respects, the viruses of the second group behave as though they may be truly obligate parasites that are immediately inactivated when the protoplasm of the living cell is destroyed, which environment in a living condition they appear to require for activity and for multiplication. In general, for virus diseases of plants, those that are transmissible by juice are also transmissible by grafting, whereas those that are not transmissible by juice are communica-

ble artificially only by grafting or by some adaptation of the grafting process.

Peach yellows, peach rosette, and little peach, frequently referred to in the present publication, are known to be infectious virus diseases. Because, under present methods, these diseases have never been successfully transmitted by juice inoculations but are readily transmitted by inoculations that involve a growth union (bud or scion), the infective principles that respectively cause yellows, rosette, and little peach, fall in the second group of viruses.

Contemporaneous with the experiments that proved the infectious nature of the phony disease, frequent microscopic examination of infected tissues failed to show a visible living organism in or associated with the cells, and laboratory cultures prepared from the infected tissues developed no fungous, bacterial or other visible growth. Therefore, because the infective principle of this disease is itself invisible even under high magnification and is not susceptible of cultivation in artificial media, and because juices expressed from infected tissues (roots) do not transmit the disease to healthy peach trees, whereas infected tissues readily and unfailingly do transmit the disease to healthy peach trees through the medium of a growth union (root-to-root graft), the infective principle that causes the phony disease is considered to be a virus and to belong to the category of those viruses that are not transmissible by means of juice.

The phony disease is therefore classified in the peach yellows group of virus diseases, because (1) it is a disease the infective principle of which appears to be similar to that which causes yellows, and (2) the principal and most important host plant for the phony disease and for peach yellows, peach rosette, and little peach is the same, namely the peach.

In behavior and in growth characters, as well as in its peculiar localization of the causal virus in one organ (root) of the plant, the phony disease differs markedly from any other known member of the peach yellows group. For all members of the group, including the phony disease, the only known method for control under orchard conditions, is eradication.

Vector not definitely determined.

Having thus classified the phony disease, the next subject of great interest and economic importance is the natural agency, or vector, by which the disease is spread from tree to tree in nature. It is well known that virus diseases as a class are very commonly carried and spread by insects, and that for the natural dissemination of certain of these diseases the requisite insect or insects are specific.

It seems logical to suppose that a vector of the phony disease may be found in the form of some root-inhabiting insect. The one insect that would appear to answer all requirements, as viewed from the standpoint of the disease and from that of the

well-known habits of the insect is the peach borer (*Aegeria exitiosa* Say.) Experiments aimed at determining whether it may be possible to communicate the phony disease from a phony to a normal peach tree through transmission of the virus by the borer are in progress, but are not sufficiently mature to indicate whether the disease may be spread by such means.

Incubation Period

The inoculations described in the preceding paragraphs pertain to the peach and were performed in January or February, when the trees worked with were in a dormant condition. The incubation period, or time that elapsed between the date of inoculation and the appearance of phony growth characters in the shoot of the inoculated tree, was about 18 months. As the natural method of inoculation is not definitely known, it is impossible to state precisely the length of the incubation period for trees infected in the natural manner. However, it would appear that in grafting a phony root piece to a branch root at a point close to the collar of the tree, the process of inoculation was carried out in a manner quite as effective as the natural method of inoculation might be, and that the incubation periods under natural and under artificial methods of inoculation may be approximately the same. Other considerations lead to a similar conclusion in spite of the conceivable advantage for rapid distribution of the virus in the root system that might obtain from inoculation during the vegetative period, when food translocation is more active.

The phony disease presents the very unusual case of a virus plant pathogen localized in one functional organ of the host, namely, the root. Of equal interest is the fact that field identification of the disease is made in an uninfected functional organ of the host, namely, the shoot. Phony roots themselves may show no macroscopic pathological characters although the infective virus is present; whereas phony shoots do exhibit definite pathological characters and changed seasonal response although the infective virus is not present.

A plausible hypothesis for explaining the relation between the infected but symptomless roots and the uninfected but visibly diseased shoots may be as follows: Sap supplied from the root system of the phony tree is toxic to the shoot, and in some manner causes the abnormal growth response that produces the disease with its characteristic symptoms. The fact that the infective virus of the phony disease seems to require living root cells for its activity and multiplication in the plant appears to support the view that the sap may transport to the shoot a deleterious root-cell by-product, possibly in the nature of a toxin or a toxin-provoking principle, rather than that the sap of the phony tree contains in unbalanced proportions the usual ingredients of normal sap. That inactivated or altered virus entities may be present in and contribute to the toxicity of the sap stream from infected roots is, of course, possible.

The termination of the incubation period, as evidenced by the development and maintenance of positive phony characters in the leafy growing shoot, is apparently dependent upon (1) the concentration or the rate of supply of the toxic principle in the sap stream from infected roots, which concentration or rate must attain or exceed a certain requisite minimum, and (2) a continuous supply of the toxic principle in the sap stream, at least throughout the vegetative periods of the shoot. The results of experimentation and of field observations, too lengthy for presentation here, lead to this interpretation.

SUMMARY

The phony disease has been rapidly increasing in prevalence and in destruction of commercial values in orchards in central Georgia, particularly during the past decade.

The disease is caused by a virus somewhat similar to the viruses causing yellows, rosette, and little peach, and requires an unusually long period of incubation to develop recognizable symptoms, two full seasons' growth ordinarily being required.

Exhaustive experiments show that the disease may be easily transmitted experimentally by root-grafting, even minute portions of roots of diseased trees being sufficient to infect the healthy trees.

The agency of spread under natural conditions has not been definitely established although much circumstantial evidence indicates that the peach borer may spread the disease.

The disease does not kill infected trees or cause any yellowing of the leaves. The foliage, in fact, usually appears more vigorous than that of healthy trees.

The branches, twigs, and fruit of the tree are greatly dwarfed and the fruit is reduced in amount, as well as in quality, with each succeeding year.

The destruction of diseased trees, as soon as symptoms of the disease can be identified, is the only method of control as yet found practicable.

ADDENDUM

Origin of the term "phony disease."

Many inquiries have been received concerning the origin of the term "phony disease". The attention of the United States Department of Agriculture was first called to this strange disorder in peach trees in 1915, by the late J. H. Hale, who at that time operated large commercial orchards in Connecticut and in Georgia. In a letter, quoted in part on page 4, Mr. Hale referred to the disorder in the "phoney trees" as a disease. Information obtained later showed that the term "pony" was originally applied to trees dwarfed by this disease, at the time of its first recorded observation in the Rumph orchards, near Mar-

shallville, Ga. When and by whom the substitution of "phoney" for "pony" was made is not known, but the former designation was in current use in 1915. In the absence of any evidence to give a clue as to the cause of this malady, the local designation "phoney trees" was modified to the extent of calling it a disease, as Mr. Hale had, and the correct dictionary spelling was substituted. The official name thus became "phony disease".